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PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON BITUMINOUS COAL

NEW DEVELOPMENTS IN UTILIZATION

NOVEMBER 15-18, 1926

CARNEGIE INSTITUTE OF TECHNOLOGY
PITTSBURGH · PENNSYLVANIA

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FOREWORD

Carnegie Institute of Technology 321 700

The first International Conference on Bituminous Coal, the proceedings of which are here presented, was planned and carried out by the Carnegie Institute of Technology through a committee of the faculty. Funds to defray the necessary expenses were advanced by the trustees of the Carnegie Institute of Technology with the understanding that this money should be repaid. Part of the sum has been collected and I am very grateful to the half dozen gentlemen who have contributed liberally.

We are deeply indebted to the members of the Advisory Board for their assistance. Without their encouragement it is doubtful whether we should have been able to carry through our plans.

Great interest has been shown in the conference. The total number registered was over 1,700, there being delegates from thirteen different countries. I have received many letters of appreciation of the work done by the Carnegie Institute of Technology in arranging the meeting. It has been impossible to acknowledge all these communications individually and I take this opportunity to thank the writers most heartily.

We are so greatly encouraged by the success of this first International Conference on Bituminous Coal that I am happy to announce that a second international congress dealing with this subject will be held at this institution in November, 1928. I shall be glad to receive suggestions as to the scope and the nature of the program from any persons who occupy themselves with the scientific study of coal or its by-products, or who are engaged in their production, marketing or utilization.

(S) THOMAS S. BAKER, *President*,
CARNEGIE INSTITUTE OF TECHNOLOGY.

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ADDRESS OF WELCOME

By Dr. Thomas Stockham Baker
President, Carnegie Institute of Technology.

In opening this International Conference on Bituminous Coal I wish first to thank the distinguished gentlemen from abroad who have made the long journey to this country and to Pittsburgh in order to place before the delegates to this meeting the results of their studies and experiments. They are adding a lustre and an authority to the Convention which make it an event of first importance in the records of science for the current year. Without their interest and cooperation, the extraordinary program which you have before you would have been impossible. And speaking for my colleagues of the faculty of the Carnegie Institute of Technology, under whose auspices this Conference is held, as well as for myself I offer them my hearty thanks.

We are also deeply indebted to the eminent American engineers and men of science who have kindly consented to take part in the proceedings. It is in a real sense an international meeting—the first, so far as I know, that has dealt with the subject of coal. The International Power Congress which was held in London in the summer of 1924 covered a broader field. We may hope that by restricting the range of the papers of this Conference it may be possible to achieve more definite and practical results.

Pittsburgh is an appropriate place in which to carry on such discussions as are about to begin, and I trust it will not be regarded as presumptuous that the Carnegie Institute of Technology should have offered itself as the sponsor for this enterprise. An educational institution may undertake the task that we have assumed without suspicion of bias or interest in any special process or method. Our object is to do a public service—a service to our community and a service to science—in inviting the greatest authorities on the treatment of soft coal to come to Pittsburgh and to our institution to submit the results of their investigations.

There can be no doubt about the importance of the subject that we shall consider. The announcement of this Conference has been received with far greater approval and enthusiasm than we had anticipated. In every corner of the civilized world coal is claiming, in a way unheard of

before, the attention of men of all classes, from the statesman to the cloistered research worker. Power is taking on an increasing importance in our lives. Cheaper power and a wider distribution of power may affect not only commerce and industry, but the very form and character of our civilation; and coal will remain the chief source of energy for generations to come. It is the foundation of our industrial fabric. When we hear of the startling transformations, or transmutations, of this basic material which the scientists whose names are on this program are accomplishing, we think of the alchemists and we feel that we are on the verge of far reaching changes with respect to the technique of producing power. We are but beginning the studies which will disclose the riches which have lain hitherto locked in coal.

It will be shown at this meeting that the liquefaction of coal is an accomplished fact. Further tests may be required to secure more economical methods of producing synthetic petroleum products, but there need be no cause for alarm at the thought of the exhaustion of natural petroleum. The coal chemist is at hand, working with the engineer, and ready to meet this emergency whenever it arises.

In less than a generation the present methods of shipping coal to be burned in its raw state under boilers hundreds of miles from the mines will appear to have been primitive and rudely unscientific. Just what form the developments of fuel technology are going to take one dare not forecast. Of one thing we are certain, and that is that the changes will be radical, and it may not be too much to hope that this present International Conference on Bituminous Coal may mark a turning point, at least in this country, in the science of the utilization of coal.

Without attempting to prophesy in detail what will be achieved at this Congress, we may state that it will illustrate in a most striking manner what can be accomplished when the principles of pure science are applied to practical questions. It will show that coal research has already revealed much—far more than the average man realizes. It will suggest that there are still extensive opportunities for further study.

Many of the great modern industries owe their origin and their prosperity to the discoveries made in the laboratory. The coal producer has profited but little by the investigations of the scientists. However, the presence here of this large number of men who are interested in the mining and the sale of coal leads to the conclusion that they too feel that they should have a share in the advantages to be secured from research. It may appear that the highly unsatisfactory condition of this industry may urge the mine owner to seek advice and assistance in a quarter to

which he has in the past rarely applied, and I believe he will secure aid if he joins his efforts with those of the scientist. The United States would do well to emulate other countries in the establishment of great foundations for the study of coal. I doubt whether any line of inquiry would lead to quicker, larger, or more profitable results.

I conceive the encouragement of research to be a duty, not only because it may promote knowledge and increase wealth; but for national, I might say patriotic reasons, we must have great laboratories directed by men of high attainments.

Farsighted men of affairs must perceive that something more than financial resources is necessary for commercial progress. Modern business demands two kinds of capital: money, and technical and scientific knowledge. A well organized and well directed staff of research men can achieve results in a business way which cannot be secured merely by great credits. The United States is now looked upon as the financial leader of the world. We shall be able to maintain this supremacy if we build up our scientific capital—if with America's wealth and the ingenuity, energy, and resourcefulness of Americans is coupled the ability to organize and carry through scientific work of a higher order.

The word "research" is beginning to have a familiar sound in the ears of American industrialists, but much remains to be done before its true meaning is realized and before we have an adequate number of gifted men to direct and do the work in the great laboratories which will be built, let us hope, in the near future. We are proud of our American scholars and engineers, and while we do not envy Europe her men of the calibre of Lander, Patart, Fischer, and Bergius, we wish for our research institutions a greater number of such original minds.

This is a meeting of scientific men from a dozen or more countries who have come together for the interchange of views. We should not overlook the benefits which proceed from such international conferences. They must serve to promote a better understanding between the nations which are represented, and with a better understanding should come mutual respect and good will. Men of science are likely to be the best messengers of peace. Furthermore, the study of coal, insofar as it increases the sum total of power that is available in the world, should contribute to better international relations. For increased power implies more rapid means of communication, and as the distance between nations is reduced in a physical sense the distance between their points of view should be decreased.

So much for the international aspects of our meeting. We hope that

it may have certain parochial, or local benefits. We hope that some of the ideas that will be brought forward may be seized upon by men of our community and put to practical use. These new ideas may mean new industries for Pittsburgh, and as our city profits by the work of scholars she may in turn strive to be famous not only as an industrial center, but also as a place where pure science is cultivated devotedly and successfully.

We are about to hear many addresses. Some of them embody the results of years of persevering investigation. Some of them show the inspiration which comes only to true men of science. The important thing is the original idea and the established certainty of the results that are behind the paper. The chemistry of coal is such a fascinating subject that one is tempted to speculate and even to romance about its future. We must guard ourselves against too much writing and hold ourselves strictly to the conception that the new age of power can only come by patient work and by the application of proved scientific principles. The future of coal is in the hands, not of the enthusiastic writer, but the industrious and indomitable student.

I wish to extend to all those who will attend these meetings a very hearty welcome. I wish to thank the foreign and American universities, the learned societies, the officials of the states and cities and the other bodies for their consideration in sending delegates to this conference, and I want to thank especially, and again, all those who have contributed to this meeting either by preparing papers or by their advice and encouragement in its preliminary stages. I am particularly indebted to the gentlemen who have been willing to serve as members of our Advisory Board. I wish you all a happy and profitable meeting.

OUR COAL SUPPLY: ITS QUANTITY, QUALITY* AND DISTRIBUTION

By MARIUS R. CAMPBELL

United States Geological Survey, Washington, D. C.

INTRODUCTION

This International Conference on Bituminous Coal has been called to consider the possibility of new and improved methods of utilizing bituminous coal so as to obviate, as far as possible, the great waste that has characterized its use, especially in this country, and by so doing secure to ourselves and to future generations a fairly adequate supply of this important fuel. Although the program of such a conference will necessarily be world-wide in its scope, it is probable that more attention will be given to the coals of the United States than to those of foreign countries, and hence it seems appropriate to open the conference with a brief description of our own supply. Such a description, though it be here applied only to the coals of the United States, may also be applicable to those of many other countries, for here we have representatives of almost every kind of coal that has been described.

The United States is blessed with a wonderful supply of coal; as a matter of fact, according to the figures submitted to the Twelfth International Geological Congress at Ottawa, Canada, in 1913, it contains more than half—52 per cent, to be exact—of the entire coal supply of the world as it was then understood. It must be remembered, however, that in many cases the figures used in that statement were uncertain and possibly unreliable and, for some regions, were more nearly in the nature of guesses than real estimates. Although the estimates referred to above may be considerably changed when more accurate data are available and the supply of this country may drop below 50 per cent of the whole, still even then we must recognize that the United States has an enormous fuel reserve. Of the forty-eight States of the Union, twenty-eight States, the territory of Alaska, and the Philippine Islands

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have a bountiful supply; eight States have only a small amount in each; and twelve States and the Hawaiian Islands are absolutely without a supply of this important fuel. The States with no coal supply of their own are Maine, New Hampshire, Vermont, Connecticut, New York, New Jersey, Delaware, South Carolina, Florida, Louisiana, Minnesota, and Wisconsin.

The possession of a nearly unlimited supply of coal has made coal-mine operators and coal users wasteful in mining and using it with the result that thousands, if not millions, of tons of the best coal of the country have been burned under such conditions that there has been no economic return, or, by wasteful methods of mining and marketing, have been lost beyond recovery. Much of this waste was due to the fact that coal was plentiful and very cheap, and also to the fact that few persons had the vision to see that our coal supply though large was limited, and that sooner or later it would be exhausted. Now, thanks to agitation by economists, geologists, and engineers, the public is awakening to the crying need of conserving our stored supply of fuel so that future generations may not suffer as a result of our wastefulness and neglect.

As the subject to be considered by this gathering is the better utilization of our coal supply, it is desirable that the renowned specialists here assembled should have at least a general knowledge, not only of the various kinds of coal that constitute that supply, but also of the estimated tonnage of each of these kinds or ranks.† For those countries whose supply consists of coal of a single rank, the problem of better utilization is comparatively simple; but for the United States it must be remembered that our coal ranges in its content of fixed carbon, on the assumption of an ash content not to exceed 8 per cent, from 25 per cent to 90 per cent; in its moisture as it comes from the mine, from 45 per cent to 1 per cent; and in heating value, from 6,000 to 14,500 British thermal units. My excuse for appearing before you is to call attention to some of these facts, with which you may not be familiar; to point out that the United States as well as other countries must consider the utilization of all her low-rank coals; and to emphasize the fact

†The term rank will be used in this paper in the same sense that it is used by the United States Geological Survey: namely, to designate those differences in coal that are due to progressive metamorphism of the vegetal material from lignite to anthracite; a change marked by the loss of moisture, oxygen, and volatile matter; and by the gain of carbon or fixed carbon, sulphur, and ash.

that in large areas of this country low-rank coals alone are available, because they are found on every hand and because high freight rates prohibit the shipment into the region of better coals.

Classification of Coal

Basis of Classification

It is not my intention to burden you with a discussion of the subject of the classification of coal, but in a description of the coal found in the United States it will be necessary to refer to the various ranks frequently; hence, in order that you may follow me without too much mental effort, I shall give them names—the same names that are used in the reports of the United States Geological Survey.

Before attempting to describe the various ranks I shall devote a few moments to a consideration of the causes which produce differences in coal and point out to you the features which I regard as significant and which should be used in determining the rank.

Differences in coal are due to various causes and conditions which may be roughly subdivided into two groups: (1) different materials from which the coal was derived, or different conditions of deposition which prevailed during its formation; and (2) pressure and heat resulting from changes in the crust of the earth, which have taken place since the coal was formed and which have changed or metamorphosed the coal so that it no longer resembles the material from which it was originally derived.

In order to understand clearly the meaning of the differences noted above, it is desirable to pause for a moment and consider the probable method of the formation of coal. Many theories have been advanced on this subject, but coal geologists of this country are almost unanimously of the opinion that coal has resulted from the hardening and compression of an accumulation of swamp vegetation which largely, if not wholly, grew in the place in which it is found today. Where the character of the vegetation differs in different parts of a swamp or the conditions of deposition are not the same, the resultant materials will be different. Thus, where the vegetation consists of trees, the material laid down on the floor of the swamp will be made up largely of logs of wood; where the vegetation is composed largely of sedges, grasses, or small shrubs, the material

being deposited will be of fine texture which, to the unaided eye, will show little if any woody structure; and where deposition goes on in a lake in the midst of an extensive swamp, such as Lake Drummond in the heart of the Dismal Swamp of Virginia, the material laid down will consist largely of seeds, spores, spore cases, and other waxy parts of the plants, which in time will be metamorphosed into cannel coal. Again, if the swamp is subjected to periods of drought, the swamp vegetation is liable to be burned, with the result that the surface is covered more or less completely with a layer of charcoal which is almost indestructible, and appears in the same form in the coal of today. Where a coal swamp suffers repeated periods of dessication, charcoal layers alternate with woody layers, forming some of the most resistant of the block coals that are known. The differences just described are sometimes very striking and result in coals having very different characteristics, but such differences are generally sporadic in their occurrence and do not indicate any particular stage in the systematic development of the coal, and therefore can not be used as criteria for its scientific classification.

Differences in coal that are due to metamorphism are, on the other hand, of the greatest importance in classification, because metamorphism affects all coals and the changes produced by it in every kind of coal are systematic in their development, regardless of the original composition of the material. By the term metamorphism is meant any and every change that takes place in coal after it has been deposited in an old coal swamp and then covered with an earthy cover, generally washed in by the streams draining into the swamp. The changes that take place are caused by pressure or heat or by a combination of the two. As soon as a coal bed has been covered by a wash of earthy material, it is more or less compressed by the weight of the superincumbent mass. If the mass is great the compression may result in the generation of sensible heat, and this heat will tend to distill the coal, driving off the more volatile portions. Later, after the coal bed has been deeply buried, it may be subjected to still greater pressures by movements within the crust of the earth which fold the strata of rock and coal, or, if still deeper in the rocky crust, the pressure that near the surface results in the formation of folds may at great depth result in the recrystallization of the rocks; and such recrystallization will

profoundly affect the coal, tending still further to drive off the volatile portion, leaving mainly the carbon and ash as a residue. In addition to metamorphism, the coal may be subjected directly to intense heat and pressure by the injection of a mass of molten material from some volcanic vent, either in the form of a volcanic stock, a dike, or an intrusive sheet or sill. Changes resulting from such local causes are generally known as local metamorphism in contradistinction to regional metamorphism, which affects a large territory and is the result of either widespread volcanism or equally widespread crustal movements.

As the processes of metamorphism are more or less continuous, the resultant changes in the once vegetal material will likewise be fairly constant and continuous, and hence it is not reasonable to expect that the processes of metamorphism in the various coal fields will be stopped at exactly the same stage in the development of the coal. Consequently, a particular kind of coal that is the result of metamorphism to a certain stage may be extensively developed in a certain field, whereas in some other field that stage may have been passed over without interruption leaving little or no coal of that particular kind. In other words, the results of coal metamorphism may be various, but it is obvious that they mark different and progressive stages in a cycle of change the end product of which is the same, though the intermediate stages may differ greatly.

The more or less gradual change due to metamorphism and the various ranks of coal and allied substances that are produced by this process are shown graphically on Fig. 1. The lower diagram represents the composition of the vegetal material and its derivatives as they are expressed in a proximate chemical analysis, after the ash has been theoretically eliminated. In this diagram the lower black blocks represent the percentage of fixed carbon, the white portion next above represents the volatile matter and the ruled portion, the moisture of the samples analyzed. The upper diagram by means of black columns represents on an arbitrary scale the heating values, expressed in British thermal units. The diagrams are so arranged that they start at the left with the lowest stage of the products of metamorphism and proceed to the right through successively higher ranks until on the extreme right is shown the highest form that a coal can assume.

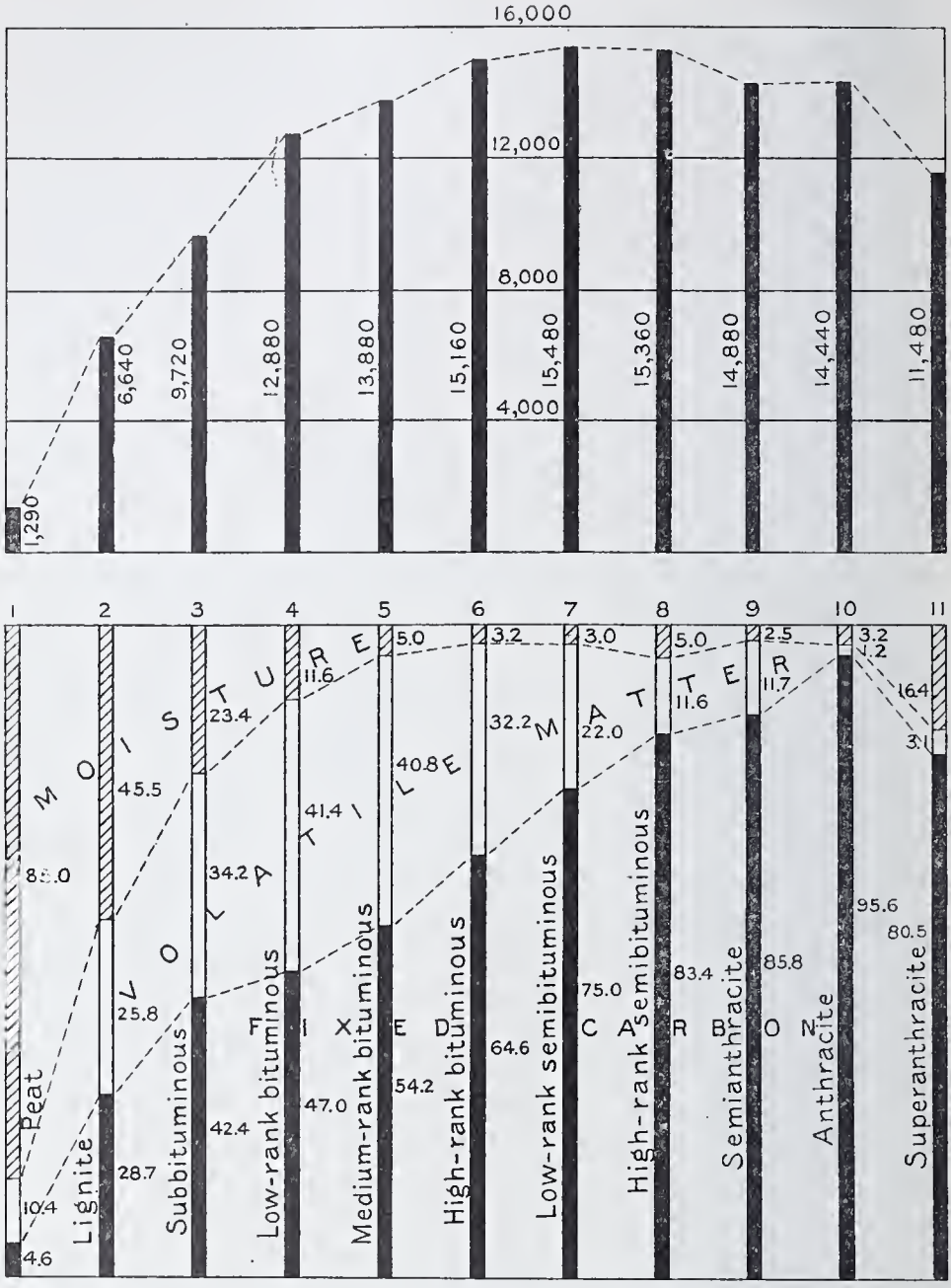


Fig. 1. Diagrams Showing the Effects of the Progressive Metamorphism of Vegetal Matter from Peat to Super-Anthracite. The Lower Diagram Represents the Chemical Composition (except ash) and the Upper Diagram, the Heating Values Expressed in British Thermal Units.

Description of Ranks

The first marked product of the metamorphism of swamp vegetation is peat. It may take on various forms, such as buried logs or branches of trees that still retain many of their original characteristics, finely divided or mascerated plant tissues, or amorphous material composed largely of the more fatty or waxy parts of plants (incipient cannel coal). Peat as it comes from the bog contains a variable percentage of ash, but after this is theoretically eliminated from the analysis, its composition, as shown on Figure 1, is about 85 per cent water, 10.4 per cent volatile matter, and 4.6 per cent fixed carbon. The great quantity of water in the peat gives it a low heating value, being only 1,290 British thermal units, as shown in the upper diagram. Before the peat can be used as a fuel a large part of the water content must be evaporated, but even then it is a poor fuel and only used where coal is not obtainable. Peat is not generally regarded as one of the ranks of coal, although it represents the lowest stage in the transformation of vegetal matter into coal.

The next product that is recognized in this country as marking a distinct rank is termed lignite, because of its generally woody character. It is considered to be the lowest rank in the scale of coals here outlined. Lignite has many of the characteristics of peat, such as being brown in color, distinctly woody or composed of finely divided plant tissues, or amorphous and representing the first stage in the development of cannel coal. The analysis of a typical lignite is shown in Fig. 1. The sample here represented has a moisture content, on the ash-free basis, of 45.5 per cent, volatile matter 25.8 per cent, and fixed carbon 28.7 per cent. Its heating value is 6,640 British thermal units. By comparing the diagram representing the lignite with that representing the peat it will be seen that the greatest difference is in the reduced amount of water in the lignite. In actual practice lignite contains from 25 to 45 per cent of moisture and on parting with this moisture the lignite shrinks and soon breaks up or "slacks" in an irregular manner. The large percentage of moisture carried by lignite, its low calorific value (from 6,000 to 7,500 British thermal units), and the property of slacking on exposure to the atmosphere, make it a very poor fuel

and one that can serve only a local community, as it can not be shipped long distances.

Sub-bituminous coal is the next rank above lignite. It is marked, as shown in Fig. 1, by a decided decrease in its moisture content to 23.4 per cent (ranging from 12 to 25 per cent), increase of volatile content to 34.2 per cent, and fixed carbon to 42.4 per cent, and a change in color from brown to black, though it still retains the slacking property which makes it fall to pieces when exposed to the weather. Like lignite, this coal must be shipped in box cars, but even when so protected it can not be economically transported to very great distances. Lignite and sub-bituminous coal are the only ranks that have the property of slacking, and this alone would serve to separate them distinctly from the coals of higher rank. Sub-bituminous coal ranges in heating value from 7,000 to 11,000 British thermal units, but its slacking property makes it a rather undesirable fuel. It is marketed mainly as a domestic fuel, and, as it can be handled without soiling the hands appreciably, it is very highly prized for this use.

The next rank above that of sub-bituminous coal is bituminous coal. The great distinction between these two ranks is that the coals of bituminous rank slack little if any on exposure to the atmosphere, whereas those of lower rank soon fall to pieces when thus exposed. In general it may be said that in passing from sub-bituminous to bituminous coal the moisture content is considerably reduced, as shown in Fig. 1, and the calorific value increased, ranging from 11,000 to about 15,000 British thermal units in the ash-free form of analysis. The bituminous rank includes several varieties that evidently owe their distinctive features to the peculiar character of the vegetation from which they were derived or to conditions of deposition. The most striking of these is cannel coal, which contains such a large percentage of volatile matter that it may be ignited with a match and when once ignited will continue to burn indefinitely. The coals in the upper part of this rank are some of the best in the country: they are excellent steaming coals, they are best adapted to the manufacture of coke, and they are the richest in gas and by-products of any coals of the country. They are not, however, well suited to domestic use as they burn with a very smoky flame that deposits an oily soot on all surrounding

objects, and on handling without gloves they soil the hands very quickly.

So far, the distinguishing features in the various ranks of coal that we have considered are entirely physical and coincide closely with the distinctions recognized by the trade, but they are rather difficult to define accurately. From the bituminous rank upward the basis of classification is that of composition, and therefore, one rank can be distinguished from another on a chemical analysis of a representative sample of the coal, provided that the lines separating the different ranks have previously been determined. As stated before, there is intergradation between the various ranks and their separation must be an arbitrary matter, which, however, can be made to coincide very closely with commercial practice and physical characteristics.

The first person in this country to recognize the various ranks in bituminous and higher coals, and to attempt their separation on the basis of chemical composition, was Persifor Frazer, of the Second Geological Survey of Pennsylvania. His scheme of classification was based on the relative percentages of volatile matter and fixed carbon, as determined in a proximate analysis. He expressed this relationship as a ratio or the quotient of the percentage of fixed carbon divided by the percentage of volatile matter, and this he called the "fuel ratio." He studied carefully the commercial practice of that day and set the limits of the various ranks of coal that he established so they would agree with it. But in the meantime the commercial practice has changed and analytical methods have been greatly improved, so that now it is necessary to redefine Frazer's terms. According to the revised scheme, bituminous coal may be defined as including all coal above the rank of sub-bituminous, whose fuel ratio does not exceed 2.5.

The next rank above bituminous coal is that of semi-bituminous, which includes the so-called "Navy" or "Smokeless" coals. The coals of this rank have fuel ratios ranging from just above 2.5 to 5. They have been so metamorphosed that they have lost most of their volatile matter, and consequently they are not well adapted to treatment for the recovery of their volatile by-products. They have been highly prized by the Navy because of their nearly smokeless character when burned in ordinary furnaces and because of

their high heating value, which ranges from a little above 12,000 to 15,400 British thermal units in the ash-free form of analysis. This rank is generally recognized as containing the great steaming coals of the United States, such as the Pocahontas of Virginia and West Virginia, the New River of West Virginia, the Georges Creek coal of Maryland, the Cambria, Somerset, and Clearfield counties coal of Pennsylvania, and the Arkansas coal west of Mississippi River. These coals are generally so highly jointed that they are exceedingly friable, breaking down largely to fine coal or slack before they reach the ultimate consumer. Because of their friability they do not make an acceptable domestic fuel, but they are well suited to the production of power, especially when used with mechanical stokers. No cannel coal is found in the semi-bituminous rank for the reason that in the metamorphism of bituminous into semi-bituminous coal the volatile matter, which is the distinguishing feature of cannel coal, is driven off and all that remains is the cannel structure without the distinguishing features of real cannel.

Some doubt has been expressed about the validity of the next higher rank, which is generally known as semi-anthracite and which Frazer regarded as intermediate between semi-bituminous coal below and anthracite above. The writer has just completed a study of the largest field of this rank of coal in the United States, and he is fully convinced that the coal in question has so many characteristics which differ from those of the coal either below or above that it deserves to be considered as a separate rank. This rank (semi-anthracite) he would define as having a fuel ratio ranging from just over 5 to 10. It is somewhat harder than bituminous coal but not so hard as anthracite; it ignites more readily than anthracite, burns at first with a short yellow flame, until the volatile matter is burned off, and then with a blue flame, until the whole is consumed. As it makes an excellent substitute for hard, dry Pennsylvania anthracite, it seems appropriate that it should bear the name anthracite, but with the prefix semi to indicate that it is not a true anthracite.

The next rank, anthracite, is well represented by the better coals of the Pennsylvania anthracite fields. Its fuel ratio is higher than that of semi-anthracite, but up to the present time no one has attempted to fix an upper limit, or, in other words, to recognize a

rank above that of anthracite. The writer feels strongly that there is another rank above anthracite, but at the present time he is unable, because of lack of data, to say positively what the upper limit of the anthracite rank should be. He is tentatively setting it at 50, but with the reservation that with more and better data it may be desirable to change this limit and probably raise it considerably. Anthracite is hard, heavy, burns with a blue flame, is difficult to ignite, and is so free from volatile matter that it burns without visible smoke and does not soil the hands on handling. Many persons think that because anthracite commands the highest price on the market it has the greatest heating value, but that is not the case, as shown in Fig. 1. Coals which have the greatest heating values are those which lie on the boundary line separating the bituminous rank from the semi-bituminous rank. Many of these coals run as high as 15,400 British thermal units in the ash-free form of analysis.

For practical purposes the rank of anthracite is the highest in this country, but in some regions the intense pressure that has been developed in the rocky crust of the earth or the great heat that has been set free from large igneous intrusions have so altered the coal that it has passed beyond the rank of anthracite and has become what the writer calls super-anthracite. Super-anthracite is more metallic in appearance than anthracite, and in places it verges on graphite. It ignites with so much difficulty that it has been said to make a good fire extinguisher. Where coal of this rank is produced by the contact of some hot igneous mass, the coal has the appearance of being baked into a dull mass that resembles neither coal nor graphite. It appears to be dead and without distinguishing features of any kind. Super-anthracite generally contains more moisture than anthracite, and, consequently, its heating value is considerably lower. It has little value as a fuel, but is of interest scientifically as apparently the final product of a long series of changes due to local or general metamorphism.

Some may think that it is a waste of time to consider the classification of coal, but the writer believes that it is one of the most important questions now before us. The necessity for immediate action is: (1) to establish standard ranks of coal which will be acceptable to operators of coal mines, dealers, consumers, chemists,

engineers and geologists and to accurately define the limits and characteristics of these ranks so they may be readily recognized and differentiated; and (2) to prevent the attempts to settle such questions by committees or commissions not at all familiar with the subject. The latter statement may seem a far cry, but frequently such questions are brought before legislative or judicial bodies in such a way that it seems absolutely necessary for them to take action.

During the past winter the definition of low-volatile coal came before the Interstate Commerce Commission and for some time it looked as though that tribunal, knowing nothing about coal, would be compelled to consider this question and determine for the scientist what should and what should not be considered low-volatile coal. The application of the Canadian tariff law also, at times, has threatened to involve the question of the classification of coal, for, according to this law, anthracite is admitted from the United States free of duty, whereas bituminous coal is taxed. The question then arises as to the dividing line between bituminous coal and anthracite. It is to be hoped that scientists who are thoroughly familiar with the various kinds of coal will agree regarding the ranks to be recognized rather than leave the decision in the hands of a tribunal whose members are not familiar with the question.

DISTRIBUTION OF COAL

General Statement

I shall now ask you to consider briefly the distribution of the coal fields and the various ranks of coal in the United States, for in determining the best method of utilizing a given coal we must not only consider its quality, but also its location with respect to the point or points at which it is to be utilized. In manufacturing as well as in other uses of coal the cost of transportation must be considered, because the coal which is intrinsically the best is not always the most economical one to use.

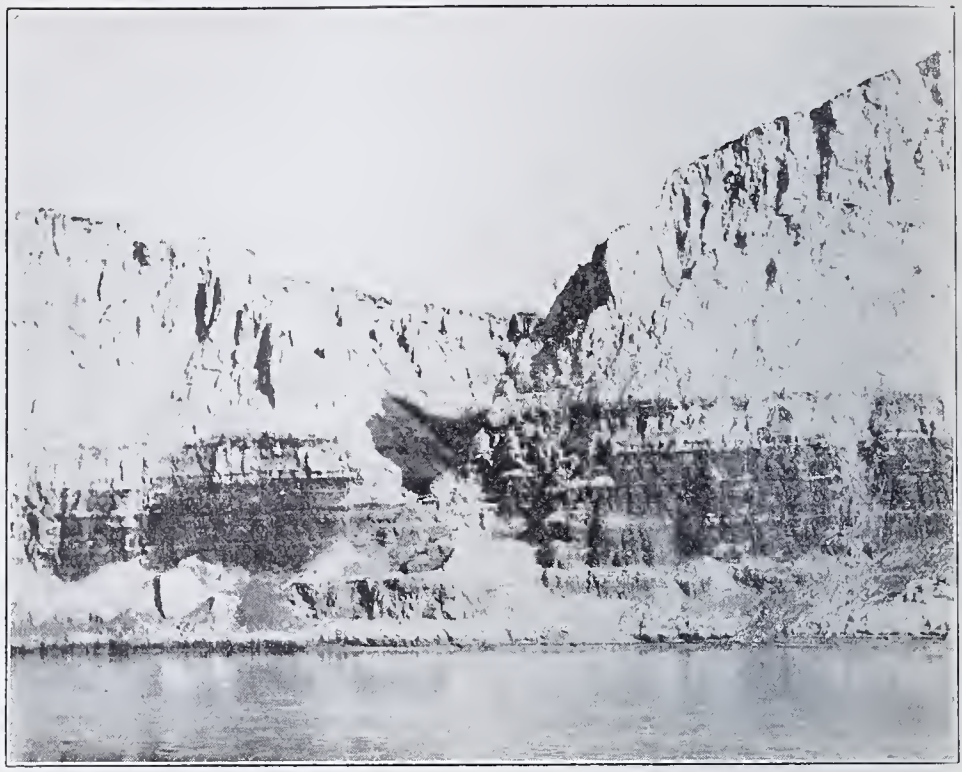
When the coals of the United States are considered in a very broad way it is apparent that there is a general increase in rank from west to east across the continent, corresponding roughly with the increase in the geologic age of the rocks in which the coals are found. Thus, in a geological sense, the oldest part of the United

States is the Appalachian region near the eastern side of the continent, and here we find the coals of highest rank, except in particular cases where the coals have been metamorphosed by local volcanic intrusions or surface flows of molten lava. West of the 100th meridian the coal-bearing rocks are generally of Cretaceous or Tertiary ages and the rank of the coal is correspondingly low, except near the mountains, where the coal has been metamorphosed by the pressure which caused the folding of the rocks and the uplifting of the range. Because of these local effects the increase in rank of the coal eastward is very irregular and in many cases reversed for short distances.

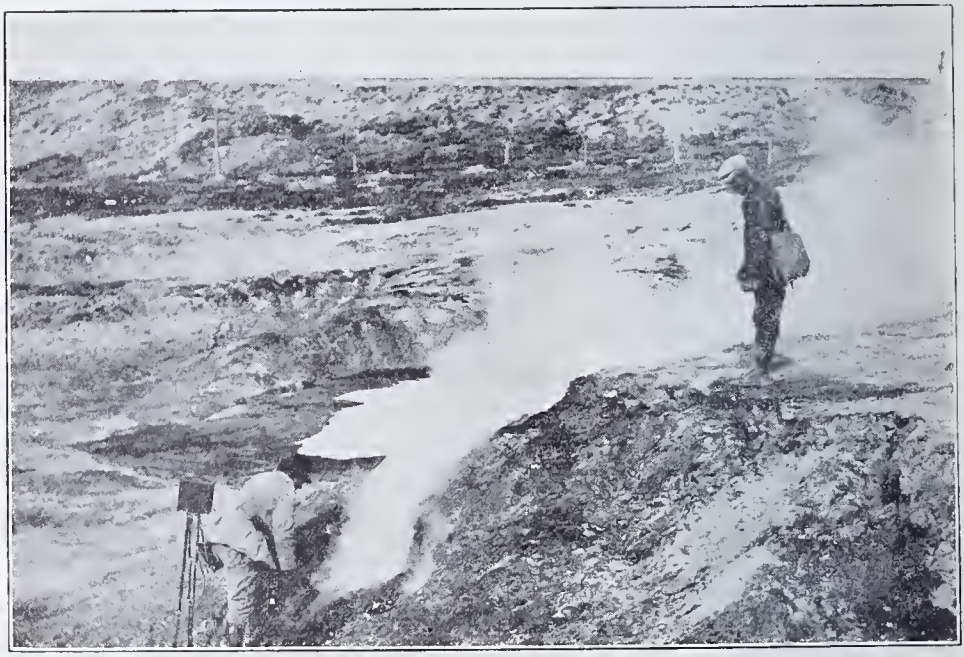
Lignite Fields

The largest field of lignite is located on the Gulf coastal plain and it coincides with the great belt of outcrop of the uppermost Cretaceous and the lowermost Tertiary rocks from the Mississippi River southwestward to the Mexican border. In this belt, lignite is mined at several places in Texas and has been prospected to some extent in Arkansas and Louisiana. East of the Mississippi River the same formations extend indefinitely, but lignite has been reported only in Mississippi and western Alabama. West of the Mississippi River lignite has been exploited to furnish fuel for domestic use and for manufacturing; but east of that great river there has been no such incentive for local development, as coal of excellent quality is mined in great abundance within easy reach and consequently few were interested enough in lignite to sink test pits to determine its thickness or quality. Much of the lignite of the Gulf Coast is very rich in volatile matter, being, in fact, incipient cannel coal. At the extreme end of the field where it crosses the Rio Grande above Laredo, the lignite has been metamorphosed into cannel coal of bituminous rank and here it has been mined for several years.

In the northern Great Plains there is a large area of lignite lying mainly in North Dakota, but extending southward a short distance into South Dakota and westward into Montana. The mining of lignite has been carried on quite extensively in North Dakota, for the rigorous winters of this region make it necessary to have an abundant supply of fuel, and each ranchman can generally dig the lignite on his own ranch. Similar conditions apply to the lignite fields of the adjoining States, and consequently the



A. LARGE LIGNITE BED EXPOSED IN THE BLUFFS OF LITTLE MISSOURI RIVER NEAR MEDORA, NORTH DAKOTA. PHOTOGRAPH BY A. G. LEONARD.



B. BURNING BED OF SUB-BITUMINOUS COAL WEST OF RAWLINS, WYOMING. PHOTOGRAPH BY E. E. SMITH.

beds of lignite are much better known than those of Texas and Arkansas. In North Dakota and Montana the local lignite has had to compete with high rank eastern coal shipped over the Great Lakes at very slight cost and then transported westward by rail to all the cities and towns. This has been a serious menace to local mining, and so the State Legislature passed an act making it incumbent on all State institutions to use lignite and thus give it an advantage over the imported fuel. Some of the lignite beds are very thick, especially those on the Little Missouri River in the western part of the State, some of which have a thickness of 35 feet. One of these beds near Medora is shown in Plate 2-A. The lignite is generally woody; in fact the writer has seen beds in the northwestern corner of the State 12 feet thick which are composed entirely of logs of wood, so slightly altered that the wood still retains its flexibility.

One of the greatest drawbacks to the general use of lignite, either on the northern Great Plains or on the Gulf Coast, is its tendency to slack on exposure to the weather. Owing to this slacking and the tendency of the fine coal to spontaneous ignition, it can not be stored for any great length of time and must be shipped in box cars so as to reach its destination in a satisfactory condition. A familiar sight, especially in the northern part of the country, is smoke arising from a burning lignite bed that has been fired by man or by the rapid oxidation of the lignite where it is exposed at the surface. Where burning continues for a long time the rocks are baked to a deep red color and in places fused to slag by the intense heat generated. A burning coal bed is shown in Plate 2-B.

Sub-Bituminous Coal Fields

The sub-bituminous coals of the United States occur only west of the 100th meridian, or, in other words, west of the middle of the Great Plains. In this great region most of the coal is found in basins lying between the ranges of the Rocky Mountains and in a relatively narrow belt directly east of the mountain front. West of the Rocky Mountains and the Wasatch Range there is little or no coal, except in the State of Washington, on the Pacific Coast. In conformity with the general scheme of treatment from the lowest to the highest ranks and from the west to the east, the sub-bituminous coal of the Pacific Coast will be the first to be considered.

PLATE 3.

A. STRIP PIT NEAR FORSYTH, MONTANA, OPERATED BY THE NORTHERN PACIFIC RAILROAD COMPANY FOR LOCOMOTIVE FUEL. THE COAL BED IS 28 FEET THICK. PHOTOGRAPH BY H. I. SMITH.

B. A COAL BED ABOUT 20 FEET THICK, EXPOSED ON SPRING CREEK IN T. 8 S., R. 40 E., MONTANA. THIS IS SUPPOSED TO BE THE DEITZ COAL BED WHICH IS MINED EXTENSIVELY AT SHERIDAN, WYOMING. PHOTOGRAPH BY C. E. DOBBIN.

The largest coal fields on the Pacific Coast of the United States are those of Washington. They lie mainly on the west side of the Cascade range of mountains, which parallels the shore line at a distance of about 120 miles. The coals occur in rocks of the Eocene period of the Tertiary era, and, therefore, they are among the youngest coals of this country. Owing to their position on the west flank of the Cascade Range, they have been subjected in several places to local metamorphism caused by the great volcanic outbursts which raised the high lava cones of Mt. Baker, Mt. Rainier, Mt. Adams and Mt. St. Helens, and by regional metamorphism caused by earth movements which have folded and faulted the rocks, producing rather complicated structures and changing the coal in their immediate vicinity from lower to higher ranks. The largest area of coal-bearing rocks lies south of Tacoma in a rather broad belt that extends southward across Columbia River a short distance into Oregon. In this large area some of the coals belong to the bituminous rank, but most of them have the characteristics of sub-bituminous coal. These coal beds have been worked at a number of places, but, owing to the proximity of coals of higher rank in the immediate vicinity and on Vancouver Island to the north, and to the heavy percentage of ash that the Washington coal contains, mining has not been very successful.

In the Rocky Mountain region one of the largest areas of subbituminous coal is that which begins near the Missouri River in the eastern part of Montana and thence extends southward in the basin between the Black Hills on the east and the Big Horn Mountain on the west and terminates at the North Platte River near the towns of Douglas and Casper. This field contains many coal beds 20 feet or more in thickness, but few of them are developed so that their full thickness can be seen. A large one, measuring 28 feet in thickness, shown in Plate 3-A, has recently been opened in a strip pit by the Northern Pacific Railroad in the vicinity of Forsyth, Montana, for locomotive use, but a much larger coal bed has been opened recently by a shaft at the town of Gillette on the Burlington Railroad in northeastern Wyoming, which is 100 feet thick. The analysis of this coal will be found on page 57.

The most important mining center in this area is at the town of Sheridan, Wyoming, on the Burlington Railroad. A number of

large mines are operated here on coal beds ranging from 8 to 24 feet in thickness, and coal is shipped both to the north and the south. Plate 3-B shows one of these coal beds 20 feet thick as it is exposed on Spring Creek, Bighorn County, Montana. Owing to its cleanliness, the coal is much prized for domestic use and, because of extensive advertising, it reaches a rather widely distributed market. Owing to its tendency to slack on exposure to the atmosphere, the coal is generally shipped in box cars, but even when so protected the amount of slacking is considerable and the distance to which shipments can be made is limited.

Other fields of sub-bituminous coal are found in this northern region, but most of them are smaller than the ones already described, and have been but little developed. The northernmost field is known as the Bull Mountain field on Musselshell River in central Montana. Some large mines have been developed at Roundup in this field for supplying coal to the Chicago, Milwaukee and St. Paul Railroad and for shipment to adjacent districts. The coal beds in the Bull Mountains range from 3 to 8 feet in thickness and the output of the mines is a fair grade of sub-bituminous coal. The most important of the smaller fields is that of Bighorn basin in northwestern Wyoming and southern Montana. This field contains a large amount of coal which has been mined quite extensively at Gebo, near Thermopolis, in the south end of the field and at Red Lodge, Montana, in the north end of the field. All of the mining and prospecting that has been done is on the rim of the basin, for it is probable that near the center the coal, if present, is certainly too deep to be mined at the present time and possibly too deep ever to be reached. The coal beds in this field are generally tilted to such an extent that mining will be more expensive than in other fields where the beds are nearly horizontal. Several small fields of sub-bituminous coal may be found in Montana: one of doubtful value on the Missouri River, south of the Bearpaw Mountains, and another in the valley of the Milk River in and about the town of Havre.

South of the Bighorn Basin there is a field of sub-bituminous coal on the headwaters of the Powder River, which extends westward across the Big Horn River. Very little coal has been mined in this field, though the coal beds showing in natural exposures are of good

PLATE 4.

A. COAL MINE SUPPLYING THE LOCAL NEEDS OF RANCHERS NEAR LAY, MOFFAT COUNTY, COLORADO. THE COAL BED IS 11 FEET 4 INCHES THICK.
PHOTOGRAPH BY H. S. GALE.

B. COAL BED 53 FEET THICK NEAR WALDEN, NORTH PARK, COLORADO.
PHOTOGRAPH BY A. L. BEEKLY.

thickness. Some time in the future these coals will doubtless be in demand, but it will be after the present generation has passed away. The country in this basin is semi-arid and there is a scanty rural population to consume the output of a mine, and towns of any size are all but unknown. Altogether, the prospect for the early utilization of this coal is not encouraging.

In passing southward the next basin of this rank of coal is a very large one, known as the Green River region, which occupies most of southwestern Wyoming and extends into Colorado just west of the main ranges of the Rocky Mountains. This field shows well the effect of local metamorphism due to the uplift of the adjacent mountains, for along its eastern border and on an interior uplift at Rock Springs, Wyoming, the coal has been changed to the bituminous rank. In the other parts that were less disturbed by the uplifts the coal is of sub-bituminous rank. The sub-bituminous coals of this great field have been developed by mines in only a few localities because the product of such mines would come in direct competition with the coals of higher rank which are mined quite extensively at Rock Springs within the field and also in adjacent fields. This great region is served by the Union Pacific Railroad which crosses it from east to west near its middle and by the Denver and Salt Lake Railroad which crosses the southeastern tip of the field in Colorado. From surface exposures and prospecting pits, such as that shown in Plate 4-A, it is known that many of the coal beds of this field have a thickness of 12 feet, and some are exposed with a thickness of 20 feet, but the unexplored condition of the coal makes it impossible to determine the number or thickness of all of the coal beds.

A small though commercially rather important coal field of subbituminous rank lies in Carbon County, Wyoming, to the east of the region just described. Though small in area, this is a deep basin and contains a large amount of coal, only a small part of which has been exploited. The field is on the main line of the Union Pacific Railroad and this company has a large mine in operation at the town of Hanna, near the center of the field. Two coal beds have been mined at Hanna, one of which has a thickness of about 20 feet and the other somewhat more than 30 feet. The coal

is shipped mainly eastward to the towns in the western part of the Great Plains, where no coal has been found.

West of the Green River region is the Hams Fork region. The rocks carrying coal are greatly disturbed in this region, being thrown into large folds and broken by profound faults. The folding has metamorphosed the coal to different degrees, some being sub-bituminous and some being of higher rank. At the village of Cumberland, on a branch line of the Oregon Short Line railroad, a bed of sub-bituminous coal which is sharply upturned has been prospected by a drift, revealing a thickness of 96 feet with only 4 inches of shaly partings to break its wonderful extent. The coal was found to be of such a low calorific value that mining was discontinued and concentrated on coals of bituminous rank. This coal bed and the one previously described as 100 feet in thickness at Gillette, in the northeastern part of the State, are the two largest coal beds so far discovered in Wyoming and also the largest that are known in the United States.

Another coal field in this vicinity that carries sub-bituminous coal is that of North Park, Colorado, which, although only slightly developed, is noted for the thick coal beds it contains. One of these beds, 53 feet in thickness, is shown in Plate 4-B. The coal beds have not been carefully traced, but there is little doubt that North Park contains a number of beds ranging from 30 feet to 77 feet in thickness. There is little demand for the coal, so the mines that have been opened are operated merely to supply the local needs. A small railroad leads into this park from Laramie, Wyoming, a town on the main line of the Union Pacific Railroad, but so far little or no coal has been shipped out over it.

Another coal field of considerable areal extent and of economic importance underlies the City of Denver, extending from the north line of the State southward as far as Colorado Springs. Mining has been carried on in this field for a great many years and the coal has found a ready market as a domestic fuel in Denver and adjacent towns and villages. It is generally referred to as the Boulder field, because its best development is in Boulder County. The coal slacks badly on exposure to the atmosphere, but as it has to be transported only a short distance, it reaches the consumer in a good condition. Its heating value is low, but on account of its cleanli-

ness and the fact that it sells for somewhat less than the higher rank coals on the south, it meets with a ready market and is highly prized. The known coal beds range in thickness up to 14 feet. Mining is generally done at comparatively shallow depths and the coal is hoisted to the surface in shafts or slopes.

One of the three great fields of sub-bituminous coal in the Rocky Mountain region is that of the San Juan River region in northwestern New Mexico and southwestern Colorado. This region extends in a north-south direction from the southern foot of the San Juan Mountains in Colorado to the main line of the Santa Fe Railroad in the vicinity of Gallup, N. M., with a prong running still farther south for a distance of about 100 miles. In the northern end of the region the coal has been metamorphosed into a good grade of bituminous coal, but in the entire region south of the San Juan River the coal is of sub-bituminous rank. Low rank coal is mined quite extensively at Gallup, N. M., on the Santa Fe Railroad. Formerly this coal was shipped in quantity to the Pacific Coast and was used by the locomotives on the railroad, but with the discovery of cheap fuel oil in southern California and its use on the railroad the demand on the Gallup mines was greatly restricted to local use in the towns and villages on the railroad in the desert region. The largest coal bed so far discovered in this region is a bed exposed on the Animas River below the city of Durango, Colorado, which measures 40 feet in thickness, but the bed contains many shale partings that detract greatly from its value for mining purposes. The coal beds at Gallup that are mined most extensively have thicknesses of about 6 feet. This coal, like most other sub-bituminous coal, is light in weight and under the forced draft of a locomotive gives off showers of sparks which caused much trouble and loss by starting fires in the grass of the plains and in the forests where they were crossed by the railroad.

There are one or two small fields of sub-bituminous coal in New Mexico and Arizona, which are generally so small as to be negligible in this description. The only exception to this statement is the Black Mesa field in the Navajo and Hopi Indian reservations in northeastern Arizona. Little is known regarding the coal beds in this field, beyond the brief fact that near some of the Indian agencies and schools small mines have been opened in order to obtain

fuel for the schools or agencies established at those points. Most of these coal beds do not exceed 5 feet in thickness, but it is possible that in the less developed parts thicker beds may be found.

As stated previously, sub-bituminous coal slacks down rapidly when exposed to the weather into a mass of fine coal which oxidizes rapidly and therefore is subject to spontaneous ignition, or to ignition by lightning or by artificial means. As a result the outcrops of most of these coal beds have been burned, producing bright red stains on the hillsides or masses of fused rock capping the buttes that are characteristic features of western landscapes. In a few places, such as that shown on Plate 2-B, fires of this kind are still burning and one may locate them by a wisp of curling smoke in the summer and by melted snow in the winter.

Sub-bituminous coal has been supposed by every one to be limited to the territory west of the Missouri River, but recently some doubt has been expressed about the correct classification of the coals of western Iowa in the bituminous rank. Because of this doubt the writer recently examined some small coal beds, which are being mined for local use, in the upper part of the Carboniferous rocks of southwestern Iowa (Taylor County). This coal has a very earthy appearance, is without well-marked joints, and will slack or crumble to pieces when exposed to the weather. An analysis of this coal is shown on page 51. As its composition and physical characteristics are similar to the composition and characteristics of a sub-bituminous coal and not at all like those of a bituminous coal, the conclusion seems obviout that this bed of coal, although formed in the Carboniferous period, is really a sub-bituminous coal and should be so classified. If this provisional conclusion can be substantiated, the interesting question will be raised as to where the line shall be drawn between the sub-bituminous coal of southwestern Iowa and the great mass of the coal of that State, as well as that of northern Missouri and western Illinois, which is universally regarded as bituminous in rank. The answer to this question can be given only when the coals of the debatable area shall have been studied more carefully and their physical characteristics as well as their chemical composition better determined.

Fields of Bituminous Coal

Although the greatest fields of bituminous coal of the United States lie east of the Great Plains, there are some large areas of this kind of coal in the Rocky Mountain region and a few small areas on the Pacific Coast; but while there are notable fields of such coal west of the Missouri River, the quality of the coal in these fields is distinctly inferior to that of the coal in the eastern fields.

The only field on the Pacific Coast that is worthy of our attention at present is that of the State of Washington. Here the coals are very young geologically, being of early Tertiary age, but they have been subjected to very severe pressure in the folding of the rocks on the flanks of the Cascade Range or have been subjected to great heat from igneous intrusions either in the form of dikes or sills, and locally have been converted to bituminous or higher ranks. The bituminous coal of Washington has been mined on a large scale for a long time. The great demand in the past and even at the present time is for a domestic coal and the bituminous coal mined here is not well suited to this use. It is high in ash, and burns with a very smoky flame—two properties which make it objectionable for household use. It was formerly used in the coastal cities as far south as Los Angeles, but in this field it was brought into direct competition with Australian and Japanese coals brought over in ballast; with Vancouver Island coal which is an excellent coal for domestic use; and later still, with fuel oil from the southern California fields. The result has been that the market for Washington coals has been shrinking steadily and the operators are facing the possibility of losing completely, or until the oil is exhausted, the coastal trade. The composition of the bituminous coal of Washington is shown on page 56.

The States of Oregon, California, Idaho, Nevada, and Arizona have very little bituminous coal to their credit. There are small areas here and there, but not enough at any one place to play an important part in the fuel supply of the region.

The Rocky Mountain region, particularly the northern portion, is poorly supplied with bituminous coal. In Montana the largest field is that which lies along the north side of the Little Belt Mountains from Great Falls eastward to the Big Snowy Mountains. In this field the coal beds are of Lower Cretaceous age and they are

neither so thick nor so pure as the coals in other geologic formations. The most important mining operation in these beds is in Sand Coulee south of the town of Great Falls, but the operators have found it difficult to compete with the sub-bituminous coals of adjacent fields and with the bituminous coals of Alberta, Canada, on the north. Considerable bituminous coal has been mined west of Livingstone and on the Yellowstone River above that town, but all of the mines have been abandoned, because of the greatly disturbed condition and impure character of the coal. Some coal just on the border line between sub-bituminous and bituminous is mined at Red Lodge, southwest of Billings, on the Northern Pacific Railroad, but the output is small and the coal is of comparatively low calorific value.

In Wyoming there are no large areas of bituminous coal, but here and there are small fields, some of which are of considerable importance. There are only two areas or fields that are worthy of our consideration. The most important of these is the dome at Rock Springs on the Union Pacific Railroad. This dome rises in the midst of the great Green River basin and on this uplift the lower coal beds are so much altered by pressure that they belong to the bituminous rank. Mining has been carried on at and near Rock Springs for a long time and the product of the mines has been widely distributed to the west and northwest as far as the Pacific Coast. The result is that Rock Springs coal is generally regarded as the type of western bituminous coal. Its composition is shown by analyses on page 57.

The Rock Springs coal is hard and blocky and stands shipment even to distant points with very little waste by breakage. It is generally low in ash and makes an excellent fuel for either domestic or manufacturing uses. There are a number of coal beds in this field ranging in thickness from 4 to 8 feet. They dip lightly and are well disposed for economical mining.

The other field of bituminous coal worthy of our consideration is the Hams Fork region, a belt of folded coal-bearing rocks that occupies much of the western margin of the State. The coal from these beds appears to be of fair quality, but mining is rather expensive and the field has with difficulty held its own in the production of coal.

Colorado contains the largest and most important fields of bituminous coal west of the Missouri River. These are: (1) The Trinidad field of Las Animas and Huerfano counties; (2) the tip end of the Uinta Basin which extends eastward from Utah into Colorado, and (3) the Durango field, that is the northern end of the San Juan River region already described under the head of sub-bituminous coal. The Trinidad field lies on the east side of the mountains in a synclinal basin which extends southward and is continuous with the Raton field of New Mexico. It is the largest field of coking coal in Colorado and the coal has been mined and coke produced here for many years, the only drawback being the high percentage of ash in the coal and the igneous dikes and sills that ray out from the Spanish Peaks. The coal beds are of good thickness, but the volcanic dikes and sills render mining expensive. The best quality of coal is found in the southern part of the basin in the vicinity of Trinidad and from this place northward the coal decreases in value to the northern extremity of the field at Walsenburg. Most of the coke consumed in the blast furnaces at Pueblo is made in the Trinidad field.

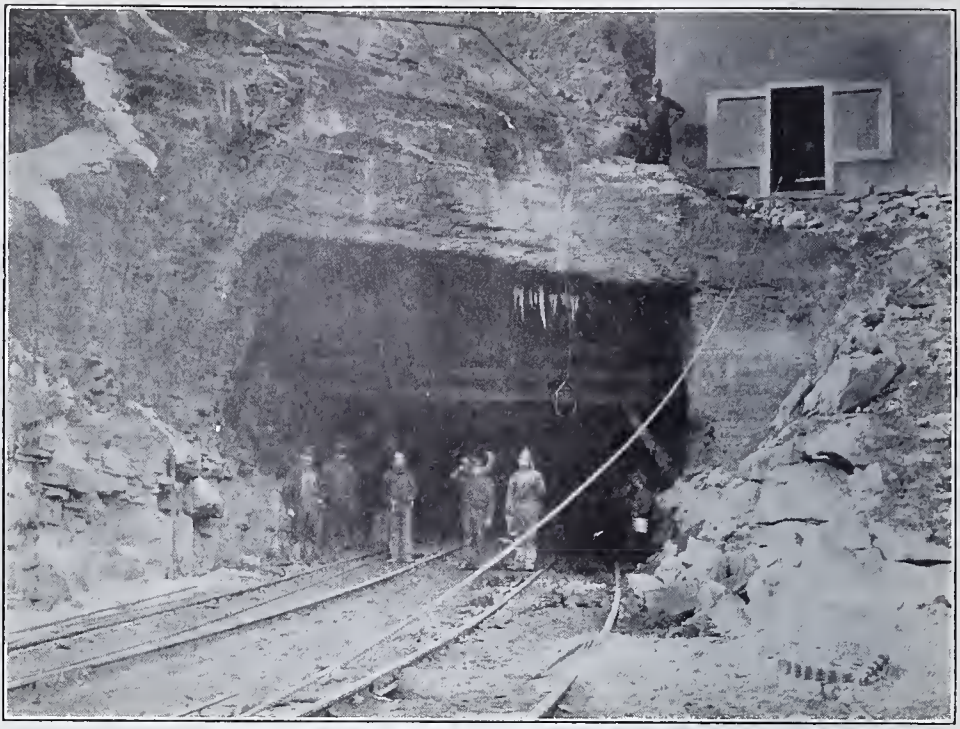
The next field in the order of importance, but the first in the order of area, is the southeastern end of the Uinta Basin which enters Colorado from the west and extends southeastward to the point of the basin in the vicinity of the town of Gunnison. The south rim of the basin is formed by the Book Cliffs north of Grand Junction and the north rim by the Grand Hogback from Newcastle to Meeker and then westward to the Utah line in the vicinity of Vernal. This great basin carries coal-bearing rocks in its rims and presumably they also extend beneath the middle of the basin, but they have not been tested except near the State line, where the floor of the basin is exposed by a cross anticline. The coal beds in this basin are worked in the vicinity of Grand Junction, in the anthracite field north of Gunnison, and at Newcastle on the Colorado River. They have been prospected on the north rim at Meeker, and in the vicinity of Rangely, but no mining of consequence has been done in this part of the basin. Some of the coal in this field southeast of Grand Junction is of sub-bituminous rank, but all in the extreme southeastern tip of the syncline is bituminous coal or coal of a higher rank. The bulk of the coal in the basin may be considered as belonging to the bituminous rank. Many of the beds

that have been mined run from 6 to 20 feet in thickness and one bed that was formerly worked at Newcastle is reported to be 40 feet in thickness. All of the mines at present in operation are on the main line or some of the branches of the Rio Grande Western Railroad.

The next field of considerable areal importance lies in the southwestern part of the State and is frequently referred to as the Durango field from the most important town in that part of the State. This field is really the northern part of the great San Juan River region of New Mexico, where the uplift of the San Juan Mountains has metamorphosed the coal from sub-bituminous to bituminous. In this field the coal beds occur in the upper part of the Cretaceous system, but the field continues a considerable distance to the northwest, embracing only thin and irregular beds in the Dakota sandstone, which is the lowermost member of the Upper Cretaceous. The coal about Durango will in places coke in a beehive oven and in the past coke was made here to serve a local iron furnace. The coal has been mined only for local use, as the steep grades over the mountains preclude its shipment into other parts of the State or into adjacent States.

A field that attracted much attention when railroad building was at its height in this State in 1874 is the Canon City coal field. The coal of this field was much sought after for locomotive use as it has comparatively high heating value and was the only field that was developed at that time. Mining has been carried on in this field ever since. The coal is suitable for manufacturing purposes, but competes with difficulty in the domestic trade with the subbituminous coal of the Boulder district. Its inability to hold its own is due to the fact that it soils the hands and produces a great quantity of oily soot when burned for heating purposes.

Other small fields of bituminous coal in this State are (1) a small field in South Park, southwest of Denver, and (2) the eastern margin of the Green River region, or, as it is locally known, the Yampa coal field, near Steamboat Springs. Owing to the proximity of the Gore Range, the coal is metamorphosed into a fair grade of bituminous coal. Mines in this field are situated on the Denver and Salt Lake (Moffat) Railroad, but up to the present time they have been badly handicapped by the expensive haul over the high summit of the Rocky Mountains at Corona. With, however, the



A. PORTAL OF A COAL MINE IN THE BOOK CLIFFS, KENILWORTH, UTAH. THE COAL BED SHOWING IN THE PICTURE IS 20 FEET THICK. PHOTOGRAPH BY J. S. BURROWS.

B. OUTCROP OF THE PITTSBURGH COAL BED NEAR CONNELSVILLE, PENNSYLVANIA, SHOWING COLUMNAR STRUCTURE. PHOTOGRAPH BY I. C. WHITE.

completion of the great tunnel under James Peak, which is now about due, that handicap will be largely removed and the coals of the Yampa field will doubtless find a wide market in the towns east of the mountains.

West of Colorado the coals of the Uinta Basin extend in good development into Utah. Bituminous coal beds are exposed on both the north and the south rim of this great basin; those on the north rim are present in great numbers where the rocks are sharply upturned on the south flank of the Uinta Mountains, but their outcrops are so badly concealed by debris coming down from the mountains that their extent on this side of the basin is not well known. On the south rim the coal beds are well exposed in the Book Cliffs, which are such a prominent feature on the north side of the Denver and Rio Grande Western Railroad. East of the Green River the coal beds are neither large nor numerous, but west of that stream they increase in size, number, and quality of coal contained, until, in the vicinity of Price, they form one of the most important coal fields of the West. The coal beds show in the Book Cliffs and in the east front of the Wasatch Plateau for a distance of over 100 miles and some of the beds are more than 20 feet in thickness. The portal of a mine showing a coal bed 20 feet thick is given on Plate 5-A. Some of the coal of this field will coke, but the major portion is a very good grade of high-volatile coal. It contains a large amount of resin, which on loaded railroad cars presents the appearance of lumps of gold in a black matrix. The field is quite extensively developed and most of the coal mined here finds a market to the west, even as far as the Pacific Coast. At Sunnyside, Utah, the coal will coke and much of the product of a large mine is converted into coke, which finds a ready market in the precious metal smelters of the mining districts about Salt Lake City.

The Wasatch Plateau field is terminated at the south by a cover of lava which has flowed out from some volcanic vent on the plateau, but still farther to the south the coal-bearing rocks are exposed in what is frequently called the Colob Plateau field. The coal here is not so good as that farther north, but the field has considerable prospective value when railroad connection is secured.

South of Colorado there are no extensive fields of bituminous coal. The most important one is the Raton field, which is the

southern extension of the Trinidad field of Colorado. Most of the coal in the New Mexico part of the field will coke, and the coke from this field supplies many of the smelters in the mining districts of southern New Mexico and Arizona. The coal beds are of considerable thickness and regularity and consequently mining conditions are extremely favorable. This field is served by the Santa Fe Railroad and the coal is transported both to the east and the west.

Two small coal fields that have attracted considerable attention in the past on account of the superior quality of their output are (1) the Cerrilos field southwest of Santa Fe and (2) the Carthage field south of Albuquerque. The Cerrillos field was noted because it produced a good grade of anthracite as the result of the intrusion of a sill of molten material just under the bed of coal. The anthracite was found to be limited in extent, but when mining was carried beyond the effect of the intrusion the coal was found to be a good grade of bituminous coal. The field is small and of little general importance. The Carthage field contains coking coal, but the rocks and the coal beds are so broken up by movements within the earth that mining was expensive and the mines found it difficult to compete with those located in the Raton field, where conditions were very much better. The field is small and of little importance.

In the San Juan Basin the bituminous coal on the southern flank of the San Juan Mountains of Colorado extends southward across the State line into New Mexico, where coal of this kind has been mined in a small way for many years. The quality deteriorates southward and bituminous coal gives way to sub-bituminous coal in a distance of about 50 miles.

The areas of bituminous coal east of the Great Plains are naturally divided into five distinct regions as follows: (1) the Southwestern Interior or Texas region; (2) the Western Interior region of Iowa, Missouri, Kansas, Oklahoma, and Arkansas; (3) the Eastern Interior region of Illinois, Indiana, and western Kentucky; (4) the Northern Interior or Michigan region; and (5) the Eastern or Great Appalachian region, embracing Pennsylvania, West Virginia, Ohio, Maryland, Virginia, Kentucky, Tennessee, Georgia, and Alabama.

The Southwestern Interior or Texas region embraces two fields: (a) the Carboniferous coals of northern Texas and (b) the metamorphosed Tertiary coals of the Rio Grande district. Neither one of these fields is of much consequence at the present time, for the reason that the coal beds are thin and irregular in their development, the coal is of only moderate heating value, and fuel oil has so displaced coal in manufacturing and the running of locomotives that there is only a limited market that hardly pays to keep the mines in operation. The coal of the northern field is a low grade bituminous coal, but that of the southern field is largely cannel which, when oil wells have ceased to produce, may become of importance in furnishing material that, by destructive distillation, may be made to pay better than they do now for the direct production of power.

The next region, the Western Interior, contains coals of various grades and ranks. All of the coal of this region, except that which occurs in Arkansas, has been classed as bituminous, but the coals even in the same rank differ widely in their composition and in their commercial value. The best coal of this region lies at the south end, in the States of Oklahoma and Kansas. Many of these coals will coke in the beehive oven and they pass by insensible gradations into the semi-bituminous coals of Eastern Oklahoma and Arkansas. The coal beds in this part of the region are of moderate thickness and continuity and they are mined by shafts, slopes, and drifts, to say nothing about strip-mining, which has been done extensively on the outcrop of the coal beds in the vicinity of Pittsburg, Kansas. North of Fort Scott, Kansas, the quality of the coal decreases steadily until in northern Missouri and Iowa the coal contains so much moisture as it comes from the mines that it is doubtful whether it can be classed as bituminous, or whether it should not more properly be considered of sub-bituminous rank. Heretofore this has been regarded as bituminous coal largely for the reason that it is of Carboniferous age, and up to the present time all coals of that geologic age have been regarded as bituminous or higher ranks. For a similar reason all of the coals west of the 100th meridian were originally designated as "lignite," but geologic work in the last 40 years has shown conclusively that geologic age is only one factor in the development of coal and that although

most of the western coals are of low rank, many of them are as high in rank as the older eastern coals. Similarly, it is now being realized that not all of the old or eastern coals are of high rank, and that in all cases the rank must be determined by a study of the coal itself and not by its geologic age. For the present the coals of northern Missouri and Iowa will be considered as belonging to the bituminous rank, but with the reservation that this classification may be changed on additional evidence. The coal beds of this part of the region are generally thin and high in ash, but owing to the wide expanse of plains to the west in which no coal is found they have a fair market and mining has been carried on steadily for a long time.

The Eastern Interior region, although much smaller in area than the one just described, is one of the most important in this part of the country. The coal of this region is similar to that of Missouri and Iowa, except that the moisture content is lower and the coal is more like normal bituminous coal than that of the other States previously mentioned. The coal beds lie in a great shallow basin and as the surface of this basin is generally flat, the coal beds are reached in the majority of cases by shafts, which at most are only a few hundred feet in depth. The deepest shaft, so far as the writer is informed, is 1,004 feet. Some of the coal can be mined out in as large blocks as the miners can handle. These blocks are very resistant to the weather, to the shocks incident to shipping, hauling, and storing the coal, and because of this resistance to breakage, the coal is highly prized as a domestic fuel. The best example of such a coal is the Brazil block coal of western Indiana, the analysis of which will be found on page 50. The coal beds are remarkably constant in character, range from 3 to 8 feet in thickness, and mining conditions are generally very good. It is a high-volatile coal and is largely responsible for the smoky atmosphere of the cities and towns in which it is used. The coal is distributed in all directions from the mines; on the west it has little to fear from the inferior coals west of the Mississippi River, but on the east it finds difficulty in competing with the higher rank coals of the Appalachian region, and consequently it is not shipped far in that direction.

The Northern Interior region is limited to a small area in Michigan, lying midway between Lake Michigan on the west and lakes

Huron and Erie on the east. It centers about the place of greatest development, which is the town of Saginaw, at the head of Saginaw Bay. The coal is of low grade, the beds are thin, and little if any of the coal is shipped beyond the limits of the State.

In passing eastward from the Mississippi Valley region one encounters the greatest coal region of the United States and certainly one of the greatest in the world when both area and quality of coal are considered. This is the well known Appalachian coal region, which stretches from the north line of Pennsylvania to central Alabama, a distance of about 800 miles. For half of its length, as measured from the north, the coal region has an average width of about 150 miles and in this part it constitutes a deep basin or trough, with the deepest part about 20 miles southeast of Parkersburg, West Virginia. As the rocks lie in the form of a trough, those in Ohio on the west side dip gently toward the southeast, and those in Pennsylvania and West Virginia on the east side dip more strongly toward the northwest. The important coal beds have been mined and prospected on both rims of the trough, but in the bottom they are absent, as shown by the logs of many oil and gas wells that have been drilled in this part of the region. Perhaps the most noted coal bed in this great basin is the Pittsburgh coal bed, (shown in Plate 5-B) which, although removed in many places by erosion, must have originally extended throughout an area of at least 15,000 square miles. In West Virginia this great bed dies out irregularly to the south, but to the north it holds a thickness which ranges from 6 to 12 feet. As the Pittsburgh coal bed stretches across most of the basin it affords an excellent opportunity to determine the amount of change caused by the metamorphism of the coal in passing from the west toward the east. The results of such an examination are shown in Figure 2, which represents the composition of this coal bed at various places on a line from west of Wheeling, West Virginia, nearly to Cumberland, Maryland, a distance of 130 miles. The analyses upon which it is based are as follows:

	1	2	3	4	5	6
Moisture	3.9	3.9	2.9	4.5	3.0	1.2
Volatile matter	43.1	39.6	33.2	30.4	20.4	17.9
Fixed carbon	43.9	48.0	55.9	58.2	67.8	73.2
Ash	9.1	8.5	8.0	6.9	8.8	7.7
B.t.u.	12,830	13,300	13,540	13,530	13,730	14,180

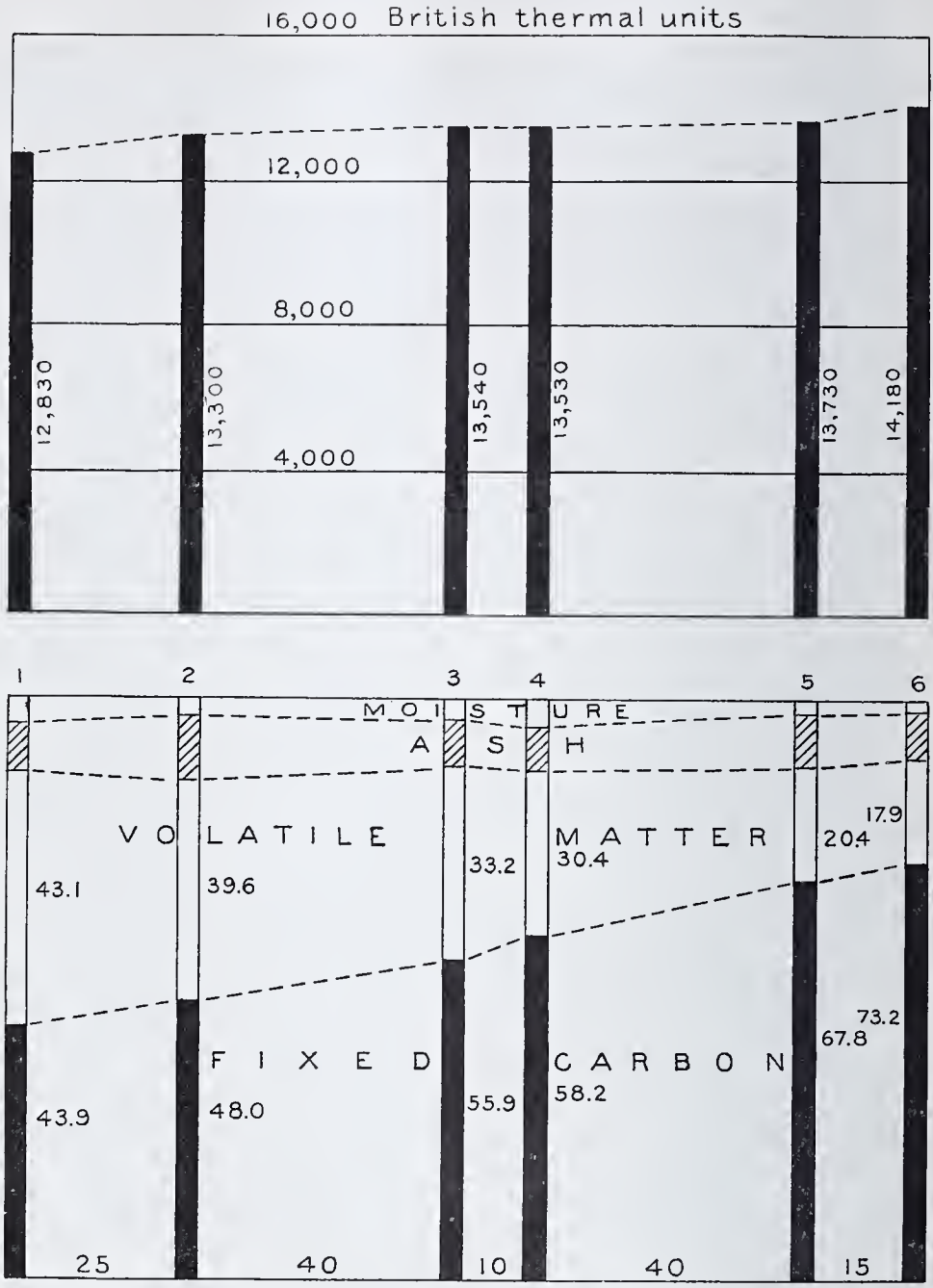


Fig. 2. Diagrams Showing the Effects of the Progressive Metamorphism of Pittsburgh Coal. The Lower Diagram Represents the Chemical Composition and the Upper One, the Heating Values. The Figures Between the Diagrams Indicates Localities: 1 is Bailey Mills, Belmont County, Ohio; 2, Martins Ferry, Ohio; 3, West Brownsville, Pa.; 4, Fairchance, Pa.; 5, Meyersdale, Pa.; and 6, Frostburg, Md.

Figures at bottom indicate distance in miles

Section 1 in Figure 2 represents the composition of the Pittsburgh coal at a point 25 miles west of Wheeling, West Virginia; section 2, in the vicinity of Wheeling; section 3, at west Brownsville, Pa., on the Monongahela River; section 4, at Fairchance, in the Connellsville basin; section 5, at Meyersdale, Somerset County, Pa., and section 6, at Frostburg, Md., a few miles west of Cumberland. In these sections the moisture and ash remain practically constant as they are not a necessary ingredient of the coal, but it is apparent that there is a gradual increase in fixed carbon, as shown by the increased size of the black blocks, and a corresponding decrease in the volatile matter. The fuel ratios at the points sampled are as follows: 1, 1.02; 2, 1,21; 3, 1.69; 4, 1.91; 5, 3.32; and 6, 4.09. The coal at point 1 is evidently bituminous and this rank holds as far east as point 4, but somewhere between points 4 and 5 (Fairchance and Meyersdale, Pa.) is the boundary between bituminous and semi-bituminous coal. The points 5 and 6, therefore, are in the semi-bituminous field. The gradation here is so perfect and regular that seemingly there can be no question that it is due to regional metamorphism which has affected the coal more than any other member of the geologic series involved.

The coal fields of Ohio, Pennsylvania, and West Virginia are so well known as scarcely to require description here. Coal mining is carried on very extensively in these States, and it was the early development of the coal, together with the nearby deposits of iron ore and limestone, that gave to this region and especially to the Pittsburgh district, its great preeminence in the manufacture of iron. In the first years of the industry raw block coal and charcoal were used in the furnaces, but they soon gave way to coke, and here, again, the Pittsburgh district controlled the situation, for the finest coking coal lay at its door. This field has produced a large amount of coke, the center of the industry being the town of Connellsville, 50 miles to the southeast. The coal fields of West Virginia are exceedingly rough and hilly, but railroads have been built up almost every valley where coal beds crop out and coal is being mined in all of the eastern counties of the States.

The coal fields of eastern Kentucky and southwestern Virginia are very similar to those of West Virginia, but they are not so systematically developed as are those farther north. The basin

narrows in a southwesterly direction, so that at Cumberland Gap, on the south line of Kentucky, it has a width of only about 55 miles. The coal beds also diminish in number and thickness in the same direction across the State of Tennessee, to the narrowest point in the entire field just north of Chattanooga, where the width is only about 35 miles and the coal beds lie so high on the Cumberland Plateau that the continuity of the field is badly broken. The coal, especially that on the east side of the field, is of good quality both for domestic and manufacturing purposes, and in a few places is suitable for the making of coke.

The most important coal-bearing State of the South is Alabama, which occupies the extreme southern end of the Appalachian coal region. Here the coal-bearing rocks have been thrown into great folds whose axes trend northeast and southwest, parallel with the general trend of the Appalachian mountains and valleys. As a result of the erosion of the anticlines, the coal fields are left in the synclines, and consequently each coal field is a separate basin which is separated from its neighbor by non-coal-bearing rocks. The larger basin on the northwest of Birmingham is known as the Warrior Basin, the next to the southeast is the Cahaba Basin, and the last in that direction is the Coosa Basin. The presence in Alabama of excellent bituminous coal in close proximity to iron ore and limestone has given to the city of Birmingham and its surrounding territory all the elements for the economical manufacture of iron, and consequently it has become the "Pittsburgh" of the south.

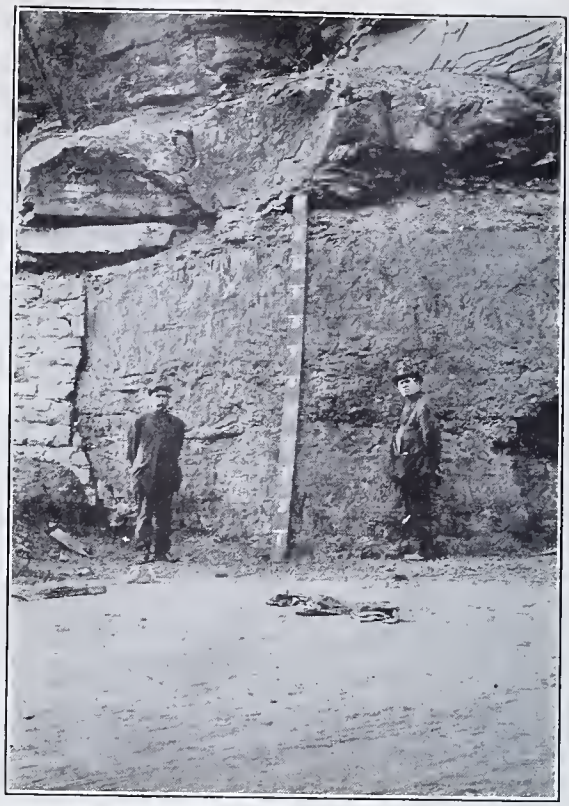
In addition to the great fields of bituminous coal already described, there are two or three small fields lying still farther to the east than the Appalachian region. These coals are of Triassic age and are of small importance except in a historical way, for in one of these, near the city of Richmond, Va., the first coal mining in the United States of which we have record was done in 1797. Another small field in similar rocks occurs southwest of Raleigh, North Carolina. The coal in these fields is of bituminous rank and will coke in ordinary beehive ovens. The rocks are greatly disturbed by faults and igneous dikes and consequently the fields are of slight importance, although the Richmond basin is favorably situated on the border of tide water.

Fields of Semi-bituminous Coal

The coals of semi-bituminous rank are restricted to small areas on the eastern side of the great Appalachian coal region, to the basin in northwestern Arkansas and the adjacent parts of Oklahoma, and to a very small area in Colorado. The most important fields of semi-bituminous or "smokeless" coal occur in Pennsylvania, Maryland, and West Virginia. These fields are due to the greater pressure that was brought to bear on the coal here than in adjacent regions, and consequently the coal has been metamorphosed by the driving off of some of its volatile constituents.

The Pennsylvania field of semi-bituminous coal is generally known by the names of the counties in which it occurs. It was first developed in a commercial manner in Clearfield County, and therefore was generally known as Clearfield coal. Later more extensive developments took place in this rank of coal in Cambria County and the coal was sent to the market under the name of Cambria coal. Still later, coal of the same rank was extensively mined in Somerset County, and it was marketed under the name of Somerset coal. These areas are in reality parts of one field which extends from near Lockhaven, Pennsylvania, to the Maryland line and which has been called by the United States Geological Survey the Windber field, from one of the most important centers of production in it. The coal beds present in the Windber field are the same as those in the bituminous fields to the west, but in an easterly direction the volatile matter decreases from 30 to 35 in the Pittsburgh district to 13 in some parts of the Windber field. Mines are in operation throughout all parts of the field in which the coal beds are of workable thickness. An isolated field lying still farther east in Pennsylvania is known as the Broadtop basin or field. The coal here is of about the same composition as that in the Windber field to the west, but the coal beds are more disturbed by folding and faulting, so that mining is more difficult than it is in the Windber field.

The next field of semi-bituminous coal is that of the Georges Creek field of Maryland. This field occupies an outlying and separate syncline in which all of the coals have been changed to the semi-bituminous rank. This coal has been mined for a great many years and now the field is facing exhaustion, especially of the thick



A. Section of the Pocahontas No. 3 Coal Bed at the Type Locality, Pocahontas, Tazewell County, Virginia. Photograph by C. A. Fisher.

B. Merrimac Coal Bed at the Empire Mine, 7 Miles North of Pulaski, Virginia. This Coal Bed is 20 Feet Thick But it Contains Many Shaly Partings Which are Separated from the Coal With Difficulty Photograph by M. R. Campbell.

beds that in the earlier days were mined at little expense on account of their size and accessibility. This field extends to the southwest into West Virginia, but in this direction the coal beds are thinner than in the Georges Creek basin and they are not so well developed commercially.

Still farther to the southwest in West Virginia, but still lying on the extreme eastern border of the Appalachian coal region, is a field which physically is only one field but in development is divided into the New River field on the northeast and the Pocahontas field on the southwest. A small part of the latter lies in the State of Virginia. The Pocahontas field is noted for the size and number of coal beds that are being mined and the field contains some of the highest-rank semi-bituminous coal in this country. All of the semi-bituminous coals are highly prized for Navy use and generally for manufacturing, because of their nearly smokeless character and their high heating values, which in some samples run as high as 14,700 B.t.u's. When these fields were first opened much of the coal was converted into coke, but as the demand for the coal in its raw condition kept increasing it became evident that its best use was not in producing metallurgical coke, but in furnishing a nearly smokeless fuel for vessels and for general manufacturing purposes. The beds in the Pocahontas field are generally thick, the original Pocahontas bed No. 3 at the type locality—Pocahontas, Va.—being as much as 12 feet in thickness. A section of this bed is shown in Plate 6-A. There are a number of other beds in this field thick enough to be worked at a profit. Owing to the great demand for this kind of coal, mines have multiplied very rapidly, with the result that the best coal of the field will be exhausted in a few score of years.

A small area of semi-bituminous coal lies in Georgia, just south of Chattanooga, Tenn. This is a small field, but produces a high grade fuel of the smokeless variety.

West of the Mississippi River there is a rather large field of semi-bituminous coal in northwestern Arkansas and eastern Oklahoma. The coal is of the same rank as the Pocahontas coal of West Virginia, but the amount of fine coal produced in mining is so large that it seriously interferes with the profitable working of the mines. As this fine coal contains only a little more ash than the lump coal, it could be readily disposed of if the field were near a manufactur-

ing center; but as this is not the case it is difficult, and at times impossible, to find a market for it.

The other field of semi-bituminous coal of any extent lies at the extreme southeastern point of the Uinta basin, in Gunnison County, Colorado. The great metamorphism of this coal is due to large volcanic outbursts that have taken place in the past, which have so heated the rocks that the volatile matter of the coal has been dissipated. Mining in this field has not been particularly successful because (1) the field is far from manufacturing cities, (2) it is served only by a narrow-gauge railroad and consequently all freight originating on it must be transshipped enroute, and (3) all outward-bound freight to the east must be hauled over one of the highest passes in the Rocky Mountains.

Semi-anthracite Fields

There is not very much coal in the United States that falls distinctly between the ranks of semi-bituminous and anthracite, but there are two or three small basins in northern Pennsylvania that contain this kind of coal and a rather large one in southwestern Virginia. There is also a small area in the extreme western end of the Southern Anthracite field of Pennsylvania, generally known as the Lykens Valley district, that contains the same kind of coal, though generally this coal is regarded as belonging to the anthracite rank. The Lykens Valley coal, however, commands a premium in the market above the hard, dry anthracite, because it is different and will ignite readily. Heretofore, outside of Pennsylvania, this coal has not been in great demand, because most of the residences in the northeastern part of the country were equipped for burning anthracite and there was no reason for their owners to look for a substitute; but, owing to the prolonged strikes in the anthracite fields and to the constantly increasing price for that kind of fuel, many householders have begun to look for a cheaper coal that will give fair satisfaction. Semi-anthracite is one of the best substitutes for real anthracite that is known to the writer, and if the high percentage of ash that is present in some of the fields could be materially reduced it would doubtless meet with a ready sale.

In the Virginia fields the coal, which is of lower Carboniferous age, extends as a narrow band across the counties of Montgomery,

A. ONE OF THE OLD WORKINGS IN THE ANTHRACITE FIELDS OF PENNSYLVANIA. PHOTOGRAPH BY HARDIN.

B. STRIPPING IN THE ANTHRACITE FIELDS OF PENNSYLVANIA. MAMMOTH COAL BED NEAR LATIMER, LUZERNE COUNTY. PHOTOGRAPH BY N. H. DARTON.

Pulaski and Wythe. The principal bed ranges in thickness from 4 to 20 feet, but it contains many bony partings, as shown in Plate 6-B, that must be removed before the coal is marketable. The mining conditions here are essentially the same as those in the anthracite fields of Pennsylvania.

Anthracite Fields

There are only two areas in the United States that deserve to be called anthracite fields. The most important of these is the great region in northeastern Pennsylvania with which most persons are more or less familiar; and the other field is in Gunnison County, Colorado. To be sure, anthracite is found in other localities in the West, where coal has been metamorphosed to the rank of anthracite by local volcanic intrusions, but such occurrences, by their very nature and mode of origin, must be of such limited extent as to be of little importance in a consideration of the fuel resources of the entire country. They will therefore be ignored in this description.

The anthracite region of Pennsylvania is made up of three distinct basins or fields, generally known as the Northern, Middle, and Southern fields. The anthracite increases in rank eastward and southward, so that the coal of highest rank is found at the eastern end of the Southern field in the vicinity of Pottsville. It decreases in rank westward in the Southern field until, at the extreme western end at Lykens Valley, the coal is only of semi-anthracite rank. It also decreases in a northerly direction, so that the coal in the northern field contains a lower percentage of fixed carbon than it does in the eastern end of the Southern basin. The coal beds in these fields vary greatly in thickness from the Mammoth bed, which in places is reported to be more than 40 feet in thickness, to beds of only a few feet in thickness, which under present conditions are too thin to mine. Methods of mining and also thickness of some of the coal beds are shown on Plate 7. The coal beds of these fields can, by means of fossil plants, be definitely correlated with the coal beds of the great bituminous coal field to the west, showing that at one time they were in all probability connected. Their separation was brought about by the development in the rocks of great folds and faults, which displaced and greatly disturbed the rocks, and by the deep cutting of erosion in the long ages that these rocks have been exposed to the action of the weather. The folding of

the rocks has greatly increased the difficulties and expense of mining, though it is hard to convince the ordinary consumer that the difficulties of mining are a sufficient justification for the present high price of the output of the mines. The demand for anthracite has been so great that mining has been pushed into almost all parts of the productive fields and the better coal is approaching exhaustion.

The Colorado anthracite is mainly limited to a small area in Gunnison County, north of the town of Gunnison. This field is of limited extent, the coal beds are greatly disturbed by rock folds and faults, and the coal when mined has to be transported over a high summit of the Rocky Mountains before it reaches a market that has more than local importance. The quality of the coal is fair, but the conditions under which it is mined are such that it is questionable whether or not it will ever yield an adequate return upon the capital invested.

There are few other anthracite mines in the west, but in most of these the character of the coal is due entirely to contact metamorphism, generally where the coal bed is close above or below an igneous sill. The best known of these local occurrences is probably the anthracite at Cerrillos, New Mexico, a short distance southwest of Sante Fe. The coal bed here lies a few feet above an igneous sill and where this distance is less than 40 feet the coal is changed into anthracite, but where the distance is greater than 40 feet the coal is of the bituminous rank. The field is small and of little commercial importance. Similar occurrences are known in Routt County, Colorado, in Iron County, Utah, and in Pierce County, Washington.

Super-anthracite Fields

In certain fields in the United States the alteration of the coal has been carried to such an extent, either through the effects of regional or of contact metamorphism, that the coal has almost passed the condition of anthracite and is more nearly in that of graphite. The largest field of this rank of coal, or super-anthracite, is in Rhode Island and southern Massachusetts. In this field, coal has been mined from time to time at Portsmouth and Providence, in Rhode Island, and at Mansfield, in Massachusetts, but none of the operations were long lived and it is doubtful if the material can ever be utilized as a fuel. At present its chief interest is in the position it holds as the uppermost member in the ranks of coal, or metamorphosed vegetal matter.

The writer is not prepared at the present time to specify definitely the difference between anthracite and super-anthracite. There seem to be certain chemical differences, but the principal distinction is probably to be found in the physical characteristics of the coal. Most of the Rhode Island super-anthracite that the writer has seen has a much higher metallic luster than has the highest rank Pennsylvania anthracite and it is generally so refractory that it can be burned with difficulty. One sample of coal from another locality, metamorphosed by the action of an igneous dike, contained about 98 per cent of carbon, and this coal was with difficulty burned in an atmosphere of pure oxygen. This material was extremely hard—so hard, in fact, that it could with difficulty be scratched with steel. Another difference that has been noted by Mr. G. C. Macfarlane, of Colorado, who has had an excellent opportunity to study the effect of local metamorphism caused by igneous sills, is that in places where the coal has been intensely baked away from the influence of air, it carries a much higher content of moisture than it does at a distance from the igneous mass. The writer feels that there is undoubtedly a rank of coal higher than the ordinary anthracite, but at the present time the evidence is not sufficient to permit of a statement of the criteria by which the two may be recognized. More study is needed to differentiate them.

ANALYSES OF REPRESENTATIVE COALS

In order that the reader may obtain an idea of the comparative value and rank of the coals of the United States, analyses of representative mine samples are tabulated on the following pages. The figures given are those obtained by the analysis of individual samples of coal, but each sample has been so selected that it represents the average composition of the coal of a certain district or field, or the composition of a certain rank of coal.

Most of the analyses given in the table were made by the Bureau of Mines or the United States Geological Survey, and so are strictly comparable; but for a few coals, as indicated, such analyses are not available and the figures given are taken from State reports.

The analysis given represents the coal as it left the mine. Such an analysis shows a larger percentage of moisture than most analyses made for private persons, because generally the samples collected by such

persons have not been sealed and the coal therefore has lost some of its moisture in transit to the laboratory. The Government analyses represent the coal as it leaves the mine and approximately as it reaches the consumer.

The analyses are as follows:

Location and rank of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Heat value (British thermal units).
ALABAMA.						
Lookout Mountain, semi-bituminous..	3.8	19.0	64.4	12.8	1.5	12,980
Blount County, bituminous.....	3.4	27.7	55.9	13.0	1.2	12,740
Birmingham district, bituminous,coking	2.4	25.9	66.8	4.9	1.5	14,490
Do.....	2.3	29.7	58.0	10.0	.8	13,490
Birmingham district, bituminous.....	1.7	31.3	60.8	6.2	1.5	14,290
Carbon Hill district, bituminous.....	4.7	31.8	53.3	10.2	1.3	12,600
Tuscaloosa district, bituminous.....	1.6	25.0	68.5	4.9	.5	14,700
Cahaba field, bituminous.....	3.1	35.0	55.8	6.1	.4	13,560
Do.....	3.2	31.0	59.6	6.2	1.2	14,140
ARIZONA.						
Black Mesa field, sub-bituminous.....	9.9	32.6	46.9	10.6	1.1	10,800
ARKANSAS.						
Russellville district, semi-anthracite...	2.1	9.8	78.8	9.3	1.7	13,700
Spadra district, semi-anthracite.....	3.1	11.4	77.0	8.5	1.8	13,790
Coal Hill district, semi-bituminous....	1.4	14.8	76.9	6.9	1.5	14,330
Paris district, semi-bituminous.....	2.8	14.7	73.4	9.1	2.8	13,770
Jenny Lind district, semi-bituminous..	1.6	17.4	73.1	7.9	1.4	14,160
Huntington district, semi-bituminous..	3.5	16.7	72.0	7.8	1.3	14,020
Camden district, lignite.....	39.4	26.5	24.4	9.7	.5	6,360
CALIFORNIA.						
Stone Canyon district, bituminous....	8.0	48.5	36.0	7.5	4.1	12,130
Mount Diablo district, sub-bituminous	15.0	38.4	34.5	12.1	5.6	9,240
Tesla district, sub-bituminous.....	18.0	39.2	26.4	16.4	3.1	8,110
Dos Rios district, sub-bituminous.....	11.4	46.8	35.7	6.1	2.6	11,180
Ione district, lignite.....	45.8	30.8	15.8	7.6	1.0	6,060
COLORADO.						
Denver field, sub-bituminous.....	18.8	30.5	44.5	6.2	.3	9,650
Do.....	25.6	28.0	41.1	5.3	.4	9,180
Colorado Springs field, sub-bituminous	26.2	29.7	37.7	6.4	.3	8,350
Canon City field, bituminous.....	9.1	35.7	48.0	7.2	.9	11,700
Trinidad field, bituminous, coking.....	2.1	32.6	52.5	12.8	.7	12,960
Trianidd field, bituminous, noncoking..	7.8	38.5	44.8	8.9	.5	11,540

Location and rank of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Heat value (British thermal units).
COLORADO—*Continued.*						
North Park field, sub-bituminous	20.0	32.5	42.5	5.0	.6	9,750
Yampa field, anthracite	7.0	3.4	75.6	14.0	.6	11,740
Yampa field, bituminous	10.4	37.9	45.5	6.2	.4	11,470
Newcastle field, bituminous	7.1	40.8	46.9	5.2	.5	12,620
Newcastle field, bituminous, coking	2.9	33.3	56.7	7.1	.5	13,720
Coal Basin field, semi-bituminous	2.4	19.4	70.8	7.4	.5	14,380
Crested Butte field, anthracite	3.0	2.9	86.6	7.5	.7	13,500
Crested Butte field, bituminous	5.6	37.6	47.6	9.2	.4	12,430
Grand Junction field, bituminous	7.6	33.6	52.9	5.9	.7	12,440
Durango field, bituminous, coking	2.7	36.1	54.5	6.7	.5	13,910
GEORGIA.						
Manlo district, semi-bituminous	2.9	17.1	72.2	7.8	.7	14,200
IDAHO.						
St. Anthony field, bituminous	11.5	37.2	47.0	4.3	.5	12,090
Goose Creek field, lignite	34.3	26.6	25.7	13.4	2.5	8,610
ILLINOIS.						
La Salle County, bituminous	13.9	37.3	38.5	10.3	3.4	10,990
Peoria County, bituminous	15.5	34.7	39.8	10.0	2.9	10,740
Fulton County, bituminous	15.7	31.4	43.1	9.8	3.0	10,620
McLean County, bituminous	10.2	35.9	40.1	13.8	2.8	11,150
Logan County, bituminous	14.8	32.9	39.7	12.6	4.0	10,410
Sangamon County, bituminous	14.3	37.2	40.3	8.2	4.4	11,010
Macoupin County, bituminous	13.3	37.1	40.7	8.9	4.1	11,160
Montgomery County, bituminous	12.7	35.5	40.2	11.6	4.2	10,670
Madison and St. Clair counties, bituminous	12.7	36.4	41.4	9.5	3.7	10,990
Marion County, bituminous	10.3	37.4	39.8	12.5	3.7	11,080
Franklin County, bituminous	9.2	33.8	48.6	8.4	.9	11,930
Williamson County, bituminous	8.8	29.9	53.8	7.5	1.1	12,220
Saline County, bituminous	6.0	32.4	54.3	7.3	1.7	12,790
Gallatin County, bituminous	3.4	35.2	52.5	8.9	2.9	13,190
INDIANA.						
Vermilion County, bituminous	10.5	39.5	39.6	10.4	4.0	11,430
Clay County, bituminous, block	15.4	32.6	46.1	5.9	2.0	11,680
Sullivan County, bituminous	13.6	35.0	44.6	6.8	1.1	11,550
Knox County, bituminous	10.6	38.1	43.0	8.3	3.7	11,750
Pike County, bituminous	11.3	38.3	43.5	6.9	3.1	11,920
Warrick County, bituminous	10.4	39.2	42.0	8.4	3.5	11,820
Vandenburgh County, bituminous	9.7	35.6	44.5	10.2	2.9	11,440

Location and rank of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Heat value (British thermal units).
IOWA.						
Boone County, bituminous*	19.5	33.4	38.3	8.8	5.4	10,520
Polk County, bituminous	14.4	37.8	36.8	11.0	5.9	10,640
Jasper County, bituminous*	9.3	39.2	39.1	12.4	2.4	11,210
Marion County, bituminous	15.7	36.9	35.8	11.6	5.1	10,290
Mahaska County, bituminous*	14.6	36.3	40.5	8.6	2.9	11,000
Lucas County, bituminous	18.7	31.8	41.8	7.7	2.4	10,510
Monroe County, bituminous	15.8	36.9	37.9	9.4	4.7	12,900
Wapello County, bituminous	11.3	38.7	39.5	10.5	4.7	11,350
Taylor County, bituminous	20.9	32.3	35.2	11.6	4.2	9,470
Appanoose County, bituminous	17.1	35.4	40.4	7.1	4.0	10,930
KANSAS.						
Leavenworth County, bituminous	12.0	35.2	39.1	13.7	4.4	10,720
Linn County, bituminous	11.1	28.8	47.5	12.6	2.4	11,220
Crawford County, bituminous	4.9	33.5	52.5	9.1	5.0	12,940
Cherokee County, bituminous	5.1	32.6	53.4	8.9	4.3	12,930
EASTERN KENTUCKY.						
Johnson County, bituminous	6.4	36.2	54.1	3.3	1.2	13,460
Johnson County, bituminous, cannel	2.2	50.6	36.7	10.5	1.0	13,750
Pike County, bituminous	2.8	36.2	56.7	4.3	1.4	14,180
Letcher County, bituminous	2.5	36.5	57.0	4.0	.6	14,150
Perry County, bituminous	3.9	37.2	54.8	4.1	.8	13,730
Laurel County, bituminous	4.5	39.9	50.8	4.8	2.3	13,510
Harlan County, bituminous	4.4	35.0	56.9	3.7	.7	13,920
Bell County, bituminous	2.8	37.8	56.3	3.1	1.0	14,240
Knox County, bituminous	4.2	36.4	53.3	6.1	.8	13,410
WESTERN KENTUCKY.						
Daviess County, bituminous	11.8	36.8	42.0	9.4	3.3	11,150
Ohio County, bituminous	10.0	36.5	44.9	8.6	2.6	11,770
Muhlenberg County, bituminous	8.8	36.2	46.4	8.6	3.6	11,900
Hopkins County, bituminous	8.5	38.0	46.4	7.1	3.5	12,340
Union County, bituminous	3.9	37.1	49.7	9.3	3.5	12,830
MARYLAND.						
Georges Creek basin, semi-bituminous, high rank	2.3	16.3	70.6	10.8	.8	13,510
Georges Creek basin, semi-bituminous, low rank	3.3	20.4	68.3	8.0	1.3	13,860
Upper Potomac basin, semi-bituminous	4.3	21.3	64.4	10.0	2.5	13,270

* Analyses made by Iowa State University.

Location and rank of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Heat value (British thermal units).
MARYLAND—*Continued.*						
Castleman basin, semi-bituminous*	2.1	22.0	67.1	8.8	2.3	13,870
Castleman basin, bituminous*	.7	24.0	66.8	8.5	1.4	13,970
Upper Youghiogheny basin, bituminous*	1.2	23.0	63.9	11.9	2.1	13,260
Lower Youghiogheny basin, bituminous*	2.3	25.5	64.4	7.8	1.1	13,780
MICHIGAN.						
Saginaw district, bituminous	11.9	31.5	49.8	6.8	1.2	11,780
MISSOURI.						
Putnam County, bituminous	18.5	32.6	39.0	9.9	4.1	10,040
Harrison County, bituminous	15.3	37.1	40.8	6.8	3.0	10,100
Adair County, bituminous	15.4	34.8	38.8	11.0	3.6	10,460
Grundy County, bituminous	11.7	38.8	38.8	10.7	5.1	11,020
Macon County, bituminous	13.8	34.7	41.8	9.7	3.3	10,960
Randolph County, bituminous	12.1	36.3	42.9	8.7	3.9	11,450
Audrain County, bituminous	10.4	39.3	38.0	12.3	4.9	11,350
Ray County, bituminous	15.8	32.8	41.5	9.9	3.0	10,620
Lafayette County, bituminous	12.3	34.4	42.0	11.3	4.6	11,000
Henry County, bituminous	10.6	37.2	40.7	11.5	3.6	11,250
Bates County, bituminous	7.8	35.5	44.0	12.7	5.2	11,740
Vernon County, bituminous	6.5	32.6	50.8	10.1	5.0	12,460
Barton County, bituminous	5.4	32.1	53.6	8.9	3.6	12,990
MONTANA.						
Culbertson district, lignite	40.8	25.2	27.8	6.2	0.7	6,150
Glendive district, lignite	34.6	35.3	22.9	7.2	1.1	7,090
Forsyth district, sub-bituminous	30.8	30.3	33.9	5.0	.3	8,120
Havre district, sub-bituminous	25.6	27.9	39.2	7.3	.6	8,290
Cutbank district, bituminous	6.6	40.3	39.2	13.9	3.1	10,930
Lewistown district, bituminous	8.0	26.6	56.1	9.3	4.4	11,510
Sand Coulee district, bituminous	6.0	28.4	51.4	14.2	2.4	11,150
Roundup district, sub-bituminous	13.4	32.4	47.6	6.6	.4	11,120
Bridger district, bituminous	9.8	27.6	46.2	16.4	.6	10,240
Bear Creek district, sub-bituminous	10.7	34.1	46.1	9.1	1.5	10,800
Red Lodge district, sub-bituminous	11.7	36.1	40.2	12.0	1.1	9,790
Missoula field, lignite	24.7	29.3	26.1	19.9	.9	6,730
NEVADA.						
Esmeralda County, bituminous	2.1	33.7	33.7	30.5	7.2	9,590

* Analyses made by the Maryland Geological Survey. Each analysis is the average of all analyses of a certain coal bed in that basin or field.

Location and rank of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash	Sulphur.	Heat value (British thermal units).
NEW MEXICO.						
Raton field, bituminous, coking	2.1	36.1	50.2	11.6	.6	12,970
Los Cerrillos field, anthracite	5.7	2.2	86.1	6.0	.7	13,270
Los Cerrillos field, bituminous	3.2	41.4	44.4	11.0	1.6	12,450
Carthage field, bituminous, coking	3.0	38.0	51.6	7.4	.9	13,260
White Oaks field, bituminous	2.5	37.9	44.9	14.7	.8	12,260
Monero district, bituminous, coking	3.0	39.0	48.3	9.7	3.5	12,930
Gallup district, sub-bituminous	12.7	36.5	43.3	7.5	.7	11,230
NORTH CAROLINA.						
Deep River field, bituminous	2.5	32.0	57.3	8.2	2.0	13,620
NORTH DAKOTA.						
Ward County, lignite*	36.5	28.4	28.7	6.4	1.4	7,650
Mountrail County, lignite*	37.8	30.1	24.3	7.8	.6	6,230
Williams County, lignite	41.1	27.2	26.3	5.4	.7	6,490
Northern McLean County, lignite*	40.0	29.7	27.1	3.2	.3	6,610
Southern McLean County, lignite	40.5	27.1	27.4	5.0	.8	6,640
Morton County, lignite	38.5	27.6	26.6	7.3	1.3	6,700
Stark County, lignite*	40.5	26.3	27.0	6.2	.8	6,210
Billings County, lignite*	37.0	26.3	28.7	8.0	1.8	6,590
Adams County, lignite	32.4	30.9	28.1	8.6	1.5	7,330
Bowman County, lignite	41.4	23.9	28.4	6.3	.7	6,240
OHIO.						
Stark County, bituminous†	6.7	36.2	48.9	8.2	2.7	12,560
Tuscarawas County, bituminous†	4.7	39.2	49.9	6.2	3.3	12,770
Jefferson County, bituminous	4.1	38.5	49.7	7.7	3.7	13,150
Coshocton County, bituminous†	4.5	38.7	50.8	6.0	3.6	12,910
Belmont County, bituminous	3.9	43.1	43.9	9.1	4.4	12,840
Guernsey County, bituminous	6.0	34.2	52.0	7.8	2.0	12,720
Noble County, bituminous	3.6	41.5	44.4	10.5	4.9	12,510
Perry County, bituminous†	6.7	37.1	49.1	7.1	2.6	12,390
Washington County, bituminous†	3.4	37.9	49.1	9.6	5.0	12,750
Hocking County, bituminous†	9.7	32.5	53.4	4.4	.5	12,250
Meigs County, bituminous†	7.2	32.8	50.7	9.3	1.3	12,000
Jackson County, bituminous	8.4	41.3	43.6	6.7	3.1	12,250
Lawrence County, bituminous	7.1	33.7	50.3	8.9	1.3	12,090
OKLAHOMA.						
Craig County, bituminous	4.1	37.4	48.3	10.2	6.1	12,920
Rogers County, bituminous	4.2	38.2	47.8	9.8	5.2	13,910
Tulsa County, bituminous	6.3	37.7	47.8	8.2	8.2	12,690
Okmulgee County, bituminous	7.5	32.9	51.0	8.6	1.5	12,410

* Analyses made by North Dakota Geological Survey.
† Analyses made by the Ohio Geological Survey.

Location and rank of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Heat value (British thermal units).
OKLAHOMA—*Continued*						
Haskell County, semi-bituminous	2.7	21.1	69.9	6.3	.8	14,100
Le Flore County, semi-bituminous	2.5	19.1	71.7	6.7	.5	14,040
Latimer County, bituminous	3.0	36.0	55.9	5.1	1.1	13,710
Pittsburg County, bituminous	3.6	33.4	58.0	5.0	.5	13,740
Coal County, bituminous	6.5	39.0	45.2	9.3	3.7	11,840
OREGON.						
Coos Bay field, sub-bituminous	18.0	31.8	39.7	10.5	2.2	8,910
Eden Ridge field, bituminous	12.6	35.0	37.7	14.7	1.3	10,350
PENNSYLVANIA.						
Anthracite region, anthracite	2.8	1.2	88.2	7.8	.9	13,300
Lykens Valley, semi-anthracite	1.1	9.6	79.5	9.8	.7	13,590
Sullivan County, semi-anthracite	3.4	9.3	75.6	11.7	.8	13,120
Tioga County, semi-bituminous	2.3	20.9	66.9	9.9	1.3	13,620
Elk County, bituminous	2.7	33.7	54.9	8.7	2.9	13,470
Center County, semi-bituminous	2.9	19.9	69.7	7.5	1.9	14,080
Center County, bituminous	3.5	23.7	61.6	11.2	2.7	13,060
Clearfield County, semi-bituminous	3.3	19.9	69.0	7.8	2.0	14,020
Indiana County, bituminous	1.0	26.1	63.8	9.1	2.7	13,950
Butler County, bituminous	4.6	33.0	54.4	8.0	1.3	13,200
Cambria County, semi-bituminous, high rank	3.3	12.5	77.9	6.3	1.0	14,340
Cambria County, semi-bituminous, low rank	2.9	21.2	70.9	5.9	1.2	14,510
Cambria County, bituminous	3.1	26.0	64.4	6.5	1.4	14,160
Westmoreland County, bituminous, coking	2.7	30.4	57.8	9.1	1.3	13,610
Allegheny County, bituminous	3.7	34.0	56.8	5.5	1.4	13,870
Broadtop field, semi-bituminous	2.1	15.5	76.0	6.4	1.1	14,470
Somerset County, semi-bituminous, high rank	2.5	12.5	78.8	6.2	1.1	14,380
Somerset County, semi-bituminous, low rank	2.6	21.5	68.0	7.9	1.7	13,900
Fayette County, bituminous, coking	2.8	30.0	59.8	7.4	1.2	13,990
Washington County, bituminous	1.4	34.6	57.8	6.2	.8	14,240
RHODE ISLAND.						
Portsmouth district, super-anthracite	13.2	2.6	65.3	18.9	.3	9,310
SOUTH DAKOTA.						
Harding County, lignite	41.3	24.0	24.3	10.2	.6	5,650

Location and rank of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Heat value (British thermal units).
TENNESSEE.						
Claiborne and Campbell counties, bituminous	3.6	37.3	55.5	3.6	1.1	13,980
Scott and Fentress counties, bituminous	3.8	38.5	51.2	6.5	1.9	13,400
Anderson County, bituminous	2.2	37.2	54.5	6.1	1.6	13,960
Morgan County, bituminous	2.0	37.5	52.6	7.9	4.0	13,810
Roane and Rhea counties, bituminous, coking	2.2	29.6	59.4	8.8	.5	13,620
Cumberland County, bituminous	4.3	25.7	62.5	7.5	.6	13,630
Overton County, bituminous	3.4	35.6	50.6	10.4	3.1	12,990
White County, bituminous	3.0	39.7	46.9	10.4	4.1	13,950
Hamilton County, bituminous	2.9	29.9	59.2	8.0	1.2	13,760
Bledsoe and Sequatchie counties, bituminous	3.0	29.8	58.9	8.3	1.0	13,560
Grundy County, bituminous	3.6	29.8	57.9	8.7	1.4	13,330
Marion County, bituminous	3.4	28.2	60.1	8.3	.8	13,430
TEXAS.						
Houston County, lignite	35.5	39.5	16.2	10.8	.6	7,140
Wood County, lignite	28.9	35.9	27.3	7.9	.5	8,000
Milam County, lignite	36.0	27.9	28.7	7.4	.8	7,130
UTAH.						
Summit County, sub-bituminous	14.2	36.0	44.8	5.0	1.4	10,630
Uinta County, bituminous	8.6	36.1	47.2	8.1	1.4	11,580
Grand County, bituminous	7.2	36.5	47.8	8.5	.7	12,060
Sunnyside, bituminous, coking	4.0	38.0	51.3	6.7	1.2	13,120
Castlegate, bituminous	2.9	40.0	51.7	5.4	.3	13,350
Mohrland, bituminous	6.3	41.6	45.7	6.4	.7	12,590
Iron and Kane counties, anthracite	8.2	4.4	58.0	29.4	2.3	8,910
Iron and Kane counties, semi-bituminous	9.5	13.2	49.2	28.1	3.6	8,860
Iron and Kane counties, bituminous	10.4	36.3	43.7	9.6	5.8	10,870
VIRGINIA.						
Appalachian region:						
Tazewell County, semi-bituminous	3.8	15.5	77.8	2.9	0.6	14,860
Buchanan County, semi-bituminous	2.4	19.6	64.6	13.4	.7	13,160
Buchanan County, bituminous	3.5	31.9	60.9	3.7	1.5	14,390
Dickinson County, bituminous	3.0	32.4	58.4	6.2	1.6	14,030
Russell County, bituminous	2.8	34.9	56.5	5.8	.6	14,150
Wise County, bituminous, coking	2.5	31.7	60.3	5.5	.5	14,250
Lee County, bituminous	3.4	34.4	58.8	3.4	.6	14,130
Montgomery County, semi-anthracite	2.1	9.7	71.1	17.1	.5	12,330
Pulaski County, semi-anthracite	2.1	10.2	68.7	19.0	1.0	12,110
Richmond Basin, bituminous	2.8	25.7	62.5	9.0	1.4	13,490

Location and rank of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Heat value (British thermal units).
WASHINGTON.						
Whatcom County, anthracite	4.4	7.4	76.0	12.2	1.0	12,590
King County:						
Newcastle district, sub-bituminous	12.1	36.8	40.7	10.4	.3	10,410
Grand Ridge district, sub-bituminous	15.9	36.0	38.5	9.6	.5	9,970
Snoqualmie district, bituminous	6.1	22.7	58.8	12.4	.9	10,710
Renton district, sub-bituminous	14.4	36.1	42.0	7.5	.6	10,560
Taylor district, bituminous	5.6	35.9	44.1	14.4	.9	11,550
Ravensdale district, bituminous	7.4	37.4	43.9	11.3	.5	11,500
Black Diamond district, bituminous	6.8	40.0	47.9	5.3	1.4	12,330
Bayne district, bituminous	4.1	32.8	52.8	10.3	.5	12,780
Pierce County:						
Burnett district, bituminous	3.2	35.0	49.3	12.5	.4	12,720
Gale Creek district, bituminous	2.8	33.8	53.9	9.5	1.0	13,450
Wilkeson district, bituminous, coking	2.5	27.7	61.3	8.5	.4	13,890
Wilkeson district, semi-bituminous	3.6	19.1	61.3	16.0	.5	12,320
Carbon Hill district, bituminous	3.4	32.2	49.5	14.9	.5	12,250
Fairfax district, bituminous	3.6	23.6	59.3	13.5	.4	12,750
Fairfax district, semi-bituminous	4.0	18.1	58.5	19.4	.5	11,820
Fairfax, district, semi-anthracite	9.2	9.4	63.7	17.7	.7	11,130
Kittias County:						
Beekman district, bituminous	3.3	34.1	50.5	12.1	.4	12,910
Roslyn district, bituminous	4.7	36.0	46.8	12.5	.4	12,240
Cle Elum district, bituminous	5.0	36.1	46.8	12.1	.4	11,900
Thurston County:						
Centralia district, sub-bituminous	21.0	33.1	36.7	9.2	.4	8,910
WEST VIRGINIA.						
Wheeling district, bituminous	4.1	36.6	53.3	6.0	2.1	13,400
Moundsville district, bituminous	3.4	41.6	48.0	7.0	3.3	13,310
Fairmont district, bituminous	2.9	34.5	56.9	5.7	.7	14,040
Clarksburg district, bituminous	2.8	38.5	53.1	5.6	2.4	14,110
Upper Potomac basin, semi-bituminous, high rank	1.1	17.2	73.8	7.9	1.1	14,490
Upper Potomac basin, semi-bituminous, low rank	1.2	20.4	70.8	7.6	1.0	14,520
Preston County, bituminous	3.6	27.4	62.8	6.2	.9	14,220
Buckhannon district, bituminous	2.5	32.5	56.3	8.7	1.7	13,590
Sutton district, bituminous*	2.3	38.3	52.9	6.5	2.1	13,530
Clay district, bituminous	2.8	35.5	54.7	7.0	.8	13,700
Winfield district, bituminous	5.0	39.6	48.3	7.1	1.8	13,000
New River field:						
New River district, semi-bituminous, high rank	4.0	14.1	73.7	8.2	.8	13,850
New River district, semi-bituminous, low rank	3.5	22.2	71.9	2.4	.7	14,690
Beckley district, semi-bituminous, high rank	4.7	13.0	77.9	4.4	.8	14,340

Location and rank of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Heat value (British thermal units).
WEST VIRGINIA—*Continued.*						
Beckley district, semi-bituminous, low rank	3.3	18.0	75.6	3.1	.8	14,660
Montgomery district, bituminous	2.4	35.5	56.7	5.4	1.0	14,160
Coalburg district, bituminous	3.4	35.2	53.1	8.3	.7	13,000
Logan district, bituminous	3.3	33.3	58.4	5.0	.7	14,050
Thacker district, bituminous, high rank	3.1	31.4	59.9	5.6	1.2	14,050
Thacker district, bituminous, low rank	4.5	38.8	50.9	5.8	2.0	13,370
Iaeger district, semi-bituminous	2.0	19.9	70.4	7.7	.7	14,110
Pocahontas field, semi-bituminous, low rank	3.4	22.5	68.8	5.3	.5	14,370
Widemouth district, semi-bituminous, medium rank	3.1	18.2	74.8	3.9	.7	14,690
Welch district, semi-bituminous, high rank	2.8	15.0	76.5	5.7	.9	14,330
WYOMING.						
Sheridan district, sub-bituminous	22.6	32.5	40.4	4.5	.3	9,220
Bighorn Basin field, sub-bituminous	16.5	32.9	45.8	4.8	.6	10,750
Campbell county, sub-bituminous, Big coal bed	30.8	30.3	33.9	5.0	.3	8,120
Black Hills region, bituminous, coking	10.0	39.1	34.3	16.6	4.9	10,250
Glenrock district, sub-bituminous	21.9	34.0	37.4	6.7	.9	9,070
Hudson district, sub-bituminous	21.1	31.4	41.7	5.8	.5	9,460
Hanna Basin field, sub-bituminous	11.5	42.6	39.3	6.6	.4	10,890
Rock Springs field, bituminous	9.8	34.3	52.5	3.4	1.0	12,260
Kemmerer district, bituminous	5.7	37.7	51.3	5.3	1.4	12,580
Kemmerer district, sub-bituminous	20.6	36.3	40.5	2.6	.5	10,240
Evanston district, sub-bituminous	14.4	36.8	41.6	7.2	.2	10,440

TONNAGE ESTIMATES

Although the general description of a coal field is very important to one considering the development of mines, or contemplating an investment in mines or mineral lands, there is another phase of the subject that is of equal if not greater importance to the political economist, and that is the quantity of coal still remaining in the ground, to which future generations may look for their supply of power and heat.

Engineers and geologists are accustomed to making estimates of the amount of coal on a given tract of land, but in general such tracts are of limited extent and have been more or less completely prospected before the engineer or geologist begins. The problem

before them is a very different one from that of making an estimate of the tonnage of coal still available in all of the coal fields of the United States. The task was gigantic, but fortunately the United States Geological Survey had been gathering information regarding various little-known fields for a number of years before the writer undertook to make the required estimate. In making private estimates engineers as a rule measure more or less carefully the area underlain by coal and also the area or areas from which the coal has been mined, and then subtract the tonnage of the mined area from that of the entire area; but manifestly in a nation-wide estimate no such procedure could be followed. It was decided, therefore, that the best way to proceed was to make an estimate of the content of a field before mining began and when that was made on sufficient evidence, it would serve as a constant quantity upon which to base future estimates, for all that would be necessary, say ten years hence, would be to compute the total tonnage mined plus the loss in mining, and subtract that from the estimated original content. Accordingly, the estimates that I shall present here were made upon that basis.

In undertaking to make an estimate of the original tonnage of coal in the ground certain assumptions must be made as a foundation, and the results attained will depend largely upon these assumptions. The principal assumptions are: (1) minimum thickness of bed of the different ranks and grades of coal that can be mined, (2) maximum depth to which mining may be carried in the different ranks of coal, (3) maximum percentage of ash that may be permitted in the various ranks of coal, (4) the percentage of waste in mining and marketing coal from the time when mining was first begun up to the time when the estimate is made, and (5) the specific gravity of the coal. As probably no two persons who have attempted to make estimates have made the same basic assumptions, so no two estimates agree as to the tonnage involved. This point is very important and is one that is usually lost sight of by the casual reader, who doubtless wonders why it is that experts disagree so widely in their estimates; whereas if he had analyzed the results a little more closely he might have found that the results were practically in accord.

Most engineers employed by corporations base their estimates on the present practice of mining and preparing coal for the market, for the mining company is controlled by these conditions, and manifestly the company will not consider a coal as minable if it lies at a depth of 4,000 feet while plenty of coal of the same kind is available at a depth not exceeding 500 feet. Similarly, a coal bed 20 inches thick will not be considered minable while other beds of coal of the same kind of much greater thickness are still available. Also, to the operator of the present time, 15 per cent of ash in a coal may prevent its sale, and therefore its mining may be impracticable; whereas if plenty of water were available and a washery were installed, 15 per cent of ash might be no bar to the mining and marketing of the coal. Most of the estimates so far made have been based on present mining conditions and practices, and hence they do not necessarily represent the tonnage that may be regarded as available 10 or even 5 years hence.

In making the estimates the following basic assumptions were made: (1) minimum thickness of bed. The minimum thickness of coal beds mined in the United States at the present time is about 15 inches; therefore, 14 inches was taken as the minimum thickness for high-rank coals, 2 feet for sub-bituminous coal, and 2.5 for lignite; (2) to meet various requirements two limits of depth were set, one of 3,000 feet for easily minable coal, and the other of 6,000 feet, which represents what is now considered as the ultimate limit of coal mining; (3) the maximum percentage of ash permissible in coal is difficult to determine, on account of the variability of the factors involved in the operation of cleaning such coals for market. Twenty-five per cent is here regarded as the limit; (4) the percentage of waste to be added to the amount mined. The percentage of waste is so variable, both in mining and in preparing coal for the market, that it is all but impossible to make a close estimate. The only safe figure seems to be to assume that the tonnage of the coal actually mined should be increased by about 50 per cent in order to allow for the waste in the coal bed being mined, in the overlying coal beds that have been rendered unminable by the operations below, and for the waste in preparing coal for the market; (5) although coals vary greatly in their weight or specific gravity, depending largely upon the percentage of ash they contain, it was

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

Estimated original tonnage of coal in the United States and the reserves at the end of 1925.

By MARIUS R. CAMPBELL

State	Lignite	Sub-bituminous coal	Bituminous coal
Alabama	.....	.....	67,583,000,000
Arkansas	90,000,000	.....	170,000,000
Arizona	.....	1,141,000,000	10,000,000
California	.....	16,000,000	27,000,000
Colorado	.....	104,175,000,000	213,071,000,000
Georgia	.....	.....	.....
Idaho	.....	100,000,000	600,000,000
Illinois	.....	.....	201,400,000,000
Indiana	.....	.....	53,051,000,000
Iowa	.....	.....	29,160,000,000
Kansas	.....	.....	30,000,000,000
Kentucky	.....	.....	123,327,000,000
Maryland	.....	.....	1,507,000,000
Michigan	.....	.....	500,000,000
Missouri	.....	.....	84,000,000,000
Montana	315,474,000,000	62,985,000,000	2,655,000,000
Mew Mexico	.....	172,906,000,000	18,925,000,000
North Carolina	.....	.....	200,000,000
North Dakota	600,000,000,000	.....	.....
Ohio	.....	.....	93,967,000,000
Oklahoma	.....	.....	46,951,000,000
Oregon	.....	7,000,000,000	3,000,000,000
Pennsylvania	.....	.....	102,574,000,000
South Dakota	1,020,000,000	.....	.....
Tennessee	.....	.....	25,665,000,000
Texas	23,000,000,000	.....	8,000,000,000
Utah	.....	5,156,000,000	88,184,000,000
Virginia	.....	.....	20,749,000,000
Washington	.....	52,442,000,000	11,412,000,000
West Virginia	.....	.....	122,644,000,000
Wyoming	.....	590,160,000,000	80,563,000,000
Miscellaneous	.....	.....	.....
Totals	939,584,000,000	996,081,000,000	1,429,895,000,000

Lignite	.....	939,584,000,000
Sub-bituminous coal	.....	996,081,000,000
Bituminous coal	.....	1,429,895,000,000
Semi-bituminous coal	.....	56,569,000,000
Anthracite and semi-anthracite	.....	22,423,000,000
Grand total	.....	3,444,552,000,000

DEPARTMENT OF THE INTERIOR
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Estimated original tonnage of coal in the United States and the reserves at the end of 1925.

By MARIUS R. CAMPBELL

State	Semi-bituminous coal	Semi-anthracite and anthracite	Production to end of 1925*
Alabama	.....	.....	466,284,242
Arkansas	1,226,000,000	400,000,000	56,442,931
Arizona	.....	.....	.....
California	.....	.....	5,153,264
Colorado	.....	100,000,000	300,356,699
Georgia	933,000,000	.....	10,359,154
Idaho	.....	.....	.....
Illinois	.....	.....	1,817,707,280
Indiana	.....	.....	522,082,456
Iowa	.....	.....	264,374,433
Kansas	.....	.....	195,366,425
Kentucky	.....	.....	617,062,455
Maryland	6,536,000,000	.....	214,741,971
Michigan	.....	.....	36,657,372
Missouri	.....	.....	168,213,235
Montana	.....	.....	81,051,165
New Mexico	.....	.....	81,627,099
North Carolina	.....	.....	635,101
North Dakota	.....	.....	16,275,450
Ohio	.....	.....	1,082,817,138
Oklahoma	8,000,000,000	.....	102,234,847
Oregon	.....	.....	2,380,313
Pennsylvania	9,574,000,000	21,000,000,000	8,030,839,494
South Dakota	.....	.....	.....
Tennessee	.....	.....	192,376,258
Texas	.....	.....	46,248,281
Utah	.....	.....	86,839,756
Virginia	400,000,000	900,000,000	216,053,380
Washington	.....	23,000,000	100,836,553
West Virginia	29,900,000,000	.....	1,855,099,638
Wyoming	.....	.....	208,937,091
Miscellaneous	.....	.....	40,127,667
Totals	56,560,000,000	22,423,000,000	16,819,181,148

Total production	.....	16,819,181,148
Loss in mining, estimated	.....	8,409,000,000
Total exhaustion	.....	25,228,181,148
Original tonnage	.....	3,444,552,000,000
Amounts produced and lost	.....	25,228,181,148
Amount available at end of 1925	.....	3,419,323,818,852

* Production for 1925, estimated.

thought best to make a general assumption rather than to attempt to estimate the specific gravity of the coal of each bed and of each field in the country. After a number of experiments, 1.3 was settled on as the average specific gravity which, although in error in certain cases, would probably be about the true average of the whole.

The table shows clearly certain features that are of the greatest interest regarding the distribution and amount of coal in the fields of the United States. It shows first that the great bulk of coal in this country is low-rank bituminous, lignite, and sub-bituminous coal, named in the order of their abundance, and that the high rank coal is relatively scarce. This is an important point in conservation, as it means that our best coal will be the first to be exhausted and that such exhaustion may occur in the not very distant future. It is also noticeable that the best steaming coal—the semi-bituminous—is limited practically to the two eastern provinces, and the exhaustion of this coal will be a far greater calamity to the country than the loss of all the anthracite, for coal of this kind has a greater efficiency and is adapted to more diverse uses than anthracite. When the output of the mines is compared with the original quantity available it is seen that the great bulk of our coal is not necessarily coming from the areas that contain the greatest quantity, but from the areas that contain the best coal. This discrepancy becomes more startling when the production of the individual States is compared with their original coal resources.

Many persons think of the eastern part of the United States as the greatest repository of coal in the country, and therefore they may be surprised to learn that there are two areas in the West that contain a greater quantity. The greatest quantity of coal originally contained in any single area of continuous coal-bearing rocks is 1,104,103,000,000 tons in the Fort Union region of Wyoming, Montana and the Dakotas; the second is 665,649,000,000 tons in the Green River region of Wyoming and Colorado; and the third is 550,989,000,000 tons in the Appalachian region of the East.

Exhaustion of Coal Supplies

The object of making such estimates as those which have just been given is to enable the reader to judge for himself whether or not the United States is in immediate danger of exhausting its coal

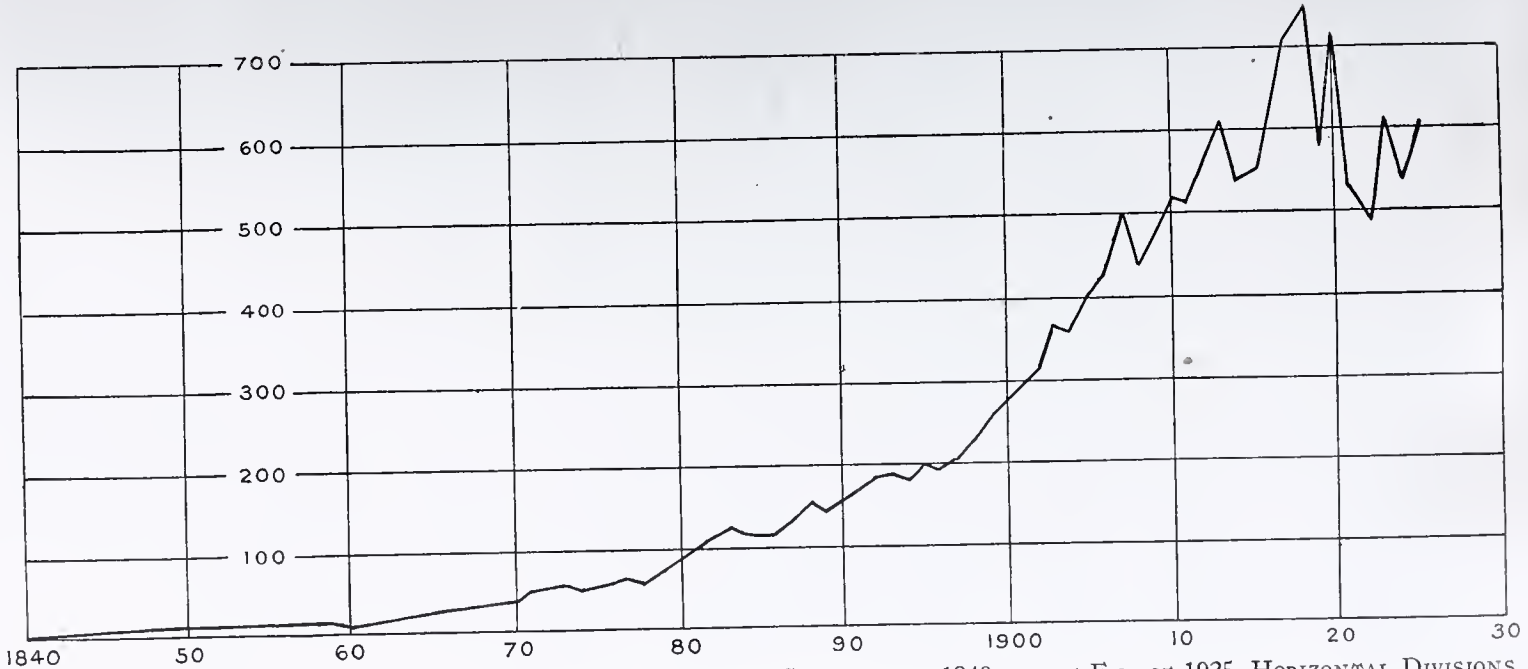

FIG. 3. GRAPH SHOWING PRODUCTION OF COAL IN THE UNITED STATES FROM 1840 TO THE END OF 1925. HORIZONTAL DIVISIONS REPRESENTED PERIODS OF 10 YEARS EACH, AND VERTICAL DIVISIONS, MILLIONS OF TONS (OF 2,000 POUND EACH).

supply. The figures given certainly do not justify such a conclusion, but if the demands of industry continue to increase in the future as they have in the immediate past, especially for the high-rank coals, it is certainly incumbent upon us to conserve our resources to the utmost, even though they now appear to be inexhaustible.

If the present rate of production, about 600 million tons a year, is maintained indefinitely and an additional 200 million tons is allowed for losses in mining and marketing, the coal supply of this country would last about 4,000 years, but will the production continue many years at this rate? Figure 3 shows the curve of production for the last 75 years, and it is impossible to conceive of this curve assuming a horizontal position for any great length of time in the future. Indeed, if one is to judge from the papers presented at this conference, the leading industrial chemists of the world are looking to coal not only to hold the field in industry already occupied by it, but in the near future to take the place now occupied by petroleum. If that is accomplished, coal will be called upon to yield its supplies much more abundantly than it has even done before and our great supply may shrink to the vanishing point in a few hundred years.

BRITISH RESEARCH ON FUEL UTILIZATION

By C. H. Lander, D.Sc., M. Inst. C.E., M.I.Mech.E., F. Inst.P.

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The question of organized research into fuel problems has assumed great prominence in Great Britain and indeed all over the world since the European war. The late George Beilby, speaking before the Institution of Civil Engineers in 1921, pointed out that "Civilization on its physical side is based on fuel" and indeed if one pauses to consider what is the main factor which differentiates the human race from the world of the lower animals it becomes apparent that whilst both require food and warmth, the human being has been able to provide the latter requirement in an artificial manner whilst the former has not. Having added to his comfort in this way, the use of fire for rudimentary industrial purposes follows naturally.

In the past the bountiful supplies of natural fuel have encouraged its use in the most wasteful manner, which in some parts of the world and especially in Great Britain has reacted against the true interests of the community both directly (by providing a smoke problem) and indirectly by encouraging improvidence in the use of a definitely wasting asset. It, however, required the stimulus of a great war to bring home the vital necessity for a reorganization in methods of fuel utilization with a view to a better use being made of our heritage of irreplacable fuels such as coal, oil, peat, shale, etc.

The writer welcomes the opportunity which this conference affords of bringing together technicians and industrialists from both sides of the Atlantic. He also feels that it is not inappropriate that a short description of the work on Fuel organized under the Department of Scientific and Industrial Research of Great Britain should be given at the opening session of the Conference. A description of this work within the limits of a lecture must necessarily be very sketchy but since it is generally agreed that amongst the most valuable features of such a conference as this are the discussion, both formal and informal, which ensue, he has in what follows tried to give a general description

of the underlying idea of the organization which has been placed in his charge together with samples of the results already achieved. For greater detail reference must be made to the published paper.*

Apart from the Government organization for Fuel Research to be described later, there are many others each studying the particular aspect of interest to them and in many cases being helped financially by the Department. Amongst these may be mentioned the Federation of British Industries (Fuel Department), the National Federation of Iron and Steel Manufacturers (Fuel Economy Committee), the Gas Investigation Committee of the Institution of Gas Engineers and the University of Leeds, as well as the Fuel Technology Departments of various Universities and Colleges, and some of the Research Associations mentioned later. With all of these the Director of Fuel Research is in close touch, as well as with many firms and individuals developing new ideas and apparatus.

Before dealing further with the particular subject of Fuel Research it seems desirable to sketch shortly the general organization of the Department of Scientific and Industrial Research, of which the Fuel Research Division is a part. The Department was formed in 1915 under a Committee of the Privy Council, who are assisted by an "Advisory Council" consisting of eminent scientists and men of affairs. The activities of the Department fall into several groups:

(1) It assists in the training of students likely to develop into useful research workers.

(2) It assists, in suitable cases, the conduct of fundamental research in University and other laboratories.

(3) It assists in co-ordinating the research carried out by various Government Departments, especially the fighting services, for their own purposes.

(4) It encourages the formation of Research Associations in the different industries for co-operative research into the problems of each industry, assisting financially at the inception of each Association, but the intention is that these should eventually be supported entirely by the industries concerned.

(5) It maintains certain Government Institutions and Organizations, which are investigating subjects such as fuel, food, etc., but

*Copies of the publications of the Department of Scientific and Industrial Research may be obtained from The British Library of Information, 8th Floor, 44 Whitehall Street, New York.

which differ essentially from the Research Associations in that there is no one existing industry which is interested in all aspects of the problems dealth with. For example, in the case of fuel practically every industry, indeed every individual, in the country is to a greater or less extent a user of fuel. The different industries such as the mining, gas, iron and steel, and electrical, to mention some of the largest, and also the domestic consumer are all vitally interested in the problems of fuel utilization, but their interests are not identical, and may be, or may appear to be, opposed.

The Research organizations supported entirely by public funds are:

(i) Building.
(ii) Food.
(iii) Forest Products.
(iv) Fuel.

In addition to the above, the department maintains:

(v) The National Physical Laboratory.
(vi) The Geological Survey of Great Britain, which fall into a somewhat different category.

Each of these organizations is under a Director, and each has a board of eminent authorities, acting in an honorary capacity, who advise as to the work to be carried out, and the methods to be adopted.

The Research Associations and the purely Government Research organizations are primarily intended for Industrial Research but this does not mean that every investigation must be undertaken with a direct utilitarian object. In many cases investigation of questions having no obvious and immediate practical application are not only justifiable but essential if real progress is to be made. Some of the investigations must necessarily prove sterile, others may lead to most valuable results, often in unexpected directions. Interesting bypaths open up continually during all investigations, and one of the most difficult of the Director's duties is to determine how far and with what priority these bypaths should be explored. While all the special government organizations mentioned have their laboratories or research stations, it frequently appears that some aspect of a problem with which one organization is more immediately concerned, can be better dealt with elsewhere, and the

close contact that results from having all these organizations under the same Department, a Department also in touch with the services and other Departments and with Universities and private laboratories, ensures true economy by making proper use of all the facilities available.

When the Fuel Research Board was appointed in 1917, with the late Sir George Beilby as Director of Fuel Research and Chairman of the Board, and with Sir Charles Parsons, Sir Richard Redmayne, and Mr. (now Sir) Richard Threlfall, as members, it was entrusted with the investigation of the nature, preparation, and use of fuels of all kinds, both in the laboratory and, where necessary, on an industrial scale. It will be noted that the reference does not include problems connected with the winning of coal which can appropriately be dealt with by a Research Association, or with Safety in Mines which is the concern of the Mines Department. To quote from the first report of the Board:

"The field to be covered by fuel research is admittedly a very wide one. It embraces enquiries into the sources and qualities of coals, of oil shales, natural oil and gas, and peat; into the methods of preparation of manufactured fuels from these natural raw materials and into the methods of consumption of the various forms of natural and manufactured forms of fuel for the production of light, heat and power. The underlying motives in these inquiries must be the securing of greater health, comfort and convenience for the community, combined with the more economical use and development of the natural resources of this country.

"It is proposed that two main lines of inquiry should be followed but should opportunities present themselves for the effective pursuit of other lines they hope they will not be compelled, either by lack of time or of assistance, to neglect these opportunities."

The two lines of inquiry referred to were: (1) physical and chemical survey and classification of the coal seams in the various districts; and (2) an investigation of the practical problems which must be solved if any large proportion of the raw fuel at present burned in its natural state is to be replaced by the various forms of fuel obtainable from coal by carbonization and gasification processes.

These lines of inquiry are not independent, as a study of the raw material is essential for the proper utilization of the material. Coal varies widely in its properties, and singularly little information

is available as to its true constitution and as to the detailed characteristics of the various seams as they occur in the ground. As regards the first line of inquiry, the collection of maps and data was begun at once, and a machinery for receiving, sifting, classifying and indexing information was organized. Much of the information available as to the coal seams proved to be unreliable; there were no standard methods of analysis, and different investigators adopted different methods of procedure. In consequence the results were not always comparable, and in the absence of information as to the exact methods adopted in each case, were even misleading. A committee was therefore appointed to examine the whole question and prepare detailed instructions for carrying out the various operations. As a result an "Interim Report on Methods of Analysis of Coal" was published in 1923. These methods have proved satisfactory, have been adopted by the Fuel Research Division for the purposes of their work, and have also been adopted, so far as they are applicable, by the Committee appointed by the Institution of Civil Engineers on standard forms of test for heat engines and boiler trials. They have been favorably received in other countries, the Statens Provningsanstalt in Sweden have agreed that they are satisfactory, and the Australian Power Survey Committee has approved of the methods as standard for use by all their Power Survey Panels throughout Australia.

A final report on methods of analysis is now completed and will be published shortly; certain minor alterations have been made in the light of experience gained since 1923, but in the main the original recommendations have remained unaltered.

In preparing these reports the Committee concerned made full use of the work of the Joint Committee of the American Chemical Society and the American Society for Testing Materials, and in many cases the American recommendations have been adopted without substantial modification. Where changes have been suggested they have been founded on the results of experiment, and made with the object of securing greater uniformity and reliability in the results. Uniformity and reliability are necessary if the full benefit is to be obtained both by scientific workers, and by industry from the many investigations being carried out in different countries. It is hoped that the standard methods adopted by various

authorities will tend more and more to uniformity as time goes on, and knowledge increases, and that in the not too distant future there will be generally accepted international standard methods.

The actual survey work in the mining districts can only be carried out with the assistance of those with local knowledge of the seams to be dealt with, and it was therefore decided to appoint local committees, one in each area, the members of which include colliery owners, managers, consumers, and representatives of the Geological Survey, the Director of Fuel Research, and of outside scientific interests. The work proceeded slowly in its early stages, as it was necessary to enlist the sympathies of the coal mining industry and to determine the best methods of procedure. Delay has been caused by the difficulties of the industry in the years following the war, and the general feeling of uncertainty that has continued with little intermission ever since. The first local committee was appointed in 1922 (Lancashire and Cheshire area) and the second in 1923 (South Yorkshire area) and work has proceeded steadily in these areas. Three more committees were appointed last year, but owing to the recrudescence of trouble in the Industry they have not yet actually started field work. Even apart from these troubles progress is slow owing to the necessity of obtaining or training suitable personnel to carry out the investigations.

The Committee mentioned above as dealing with methods of analysis is also dealing with the more difficult question of methods of sampling. Satisfactory methods have been devised for sampling a coal seam *in situ* and these are in use for the purposes of the survey; also for sampling a consignment for special tests, such as boiler trials, etc. The most difficult problem, however, is that of obtaining a fair sample of a large commercial consignment, such as a cargo of coal for export, and it is noteworthy that disputes between foreign purchasers and our exporters generally turn on the methods of sampling adopted. Much information on the subject has been collected, and experiments have been carried out at the Fuel Research Station and elsewhere, including cargo sampling in conjunction with the Swedish Statens Provningsanstalt; it is hoped it will shortly be possible to make some recommendations on this urgent question.

The work of the Survey is not confined to laboratory tests, but where necessary tests of large consignments are made at the Fuel Re-

search Station, for example, on the behavior of the coal in gas retorts. Consideration is also given to the methods of preparing the coal for the market, e. g., by separating portions of a seam, by blending, or by cleaning; as the organization develops further it will be possible to do more in these directions. The effect of increased knowledge of the characteristics of the seams and of processes for treating coal before it is burned, is cumulative, the one line of investigation reacting on the other.

It should be stated that the work of the Physical and Chemical Survey of the National Coal Resources does not conflict with that of the Geological Survey, which is also under the Department of Scientific and Industrial Research, The two organizations maintain the closest touch and co-operation.

The second line of inquiry involves a detailed study of carbonization in general and of other processes suggested from time to time. Such problems cannot be finally solved by small scale work in the laboratory; the development of any process from a laboratory to a works scale always presents difficulties, and in the class of work here in question the scale effect is pronounced and at present practically incalculable owing to the complicated factors involved. For these reasons a Fuel Research Station was erected, on the recommendation of Sir George Beilby and to his designs, where trials could be carried out on units of full commercial size, but with the accuracy usually associated only with laboratory work. The author has on many occasions had the pleasure of showing American fuel experts over the station and of discussing with them various aspects of the problems dealt with.

Development of the Research Program

High Temperature Carbonization

Shortly after its appointment the Board was asked to advise as to "the most suitable composition and quality of gas and the minimum pressure at which it should be supplied, having regard to the desirability of economy in coal, the adequate recovery of by-products, and the purposes for which gas is now used." The recommendations made were in the main embodied in the Gas Regulation Act of 1920, and included the adoption of the "therm" basis for charging for gas. This enabled gas undertakings to adopt that method of gas manufacture most suitable to the local conditions in each case. To assist the industry

in determining the most suitable methods to adopt, many experiments have been since carried out, using a number of typical gas coals in plants of various types.

For the purpose of some of these tests a setting of four commercial (high temperature) gas retorts, of the continuously working vertical type was installed. The nominal throughput of the setting was ten tons of coal a day. The retorts themselves are of standard pattern, but the firing arrangements and other circumstances of the plant were modified in some respects in order to facilitate exact measurement of all the factors involved. These retorts were first used to determine, for a number of typical coals, the effect of introducing steam to the base of the retort during carbonization. It was found that in all cases the total thermal value of the gas produced per ton of coal and the quantities of tar and sulphate of ammonia were considerably increased at the expense of a reduction (of less value) in the amount of coke, a possible disadvantage being that the calorific value of the gas was somewhat lowered. The increased bulk of gas produced, however, more than compensated for this and the total "therms" of gas per ton of coal was increased, in some cases by as much as 30 per cent. Similar tests were carried out at about the same time by the Institution of Gas Engineers, using retorts in the Uddington Gas Works. The results agreed closely and have been correlated with those obtained at the Fuel Research Station. The general effect of "steaming" was known, but previous to these tests, which have proved of great value to the gas industry, few reliable quantitative data were available.

Since the publication of the first set of steaming tests the work has been extended to cover other varities of gas coals. In several cases large quantities of coal have been provided by Gas Companies and Collieries so that information might be afforded on varieties which present points of difficulty. In all, the behavior in retorts, with varying percentages of steam, of nine different varieties have been investigated.

The retorts have also been used to provide information on the working of certain foreign coals. In one case the contract for a large foreign gas works was secured by a British firm following upon the successful working, through the station retorts, of 50 tons of the actual coal to be used.

Each "test" of this nature occupies three to five days continuous working under the stated conditions, and involves the carbonization of

30-60 tons of coal. A test of this length is necessary to insure that the results shall not be vitiated by the inevitable uncertainty as to the amount of material in the retort system at the beginning and end of the test. All material entering and leaving the system is weighed or measured, and no test is considered satisfactory unless a reasonable balance is obtained between the quantities of material entering and leaving the system. The errors actually obtained are under one per cent, unless large quantities of steam are used, when the weight unaccounted for may increase to a little over 3 per cent, probably due to leakage of condensed steam from the bottom of the retort.

An investigation has been carried out on the conditions of using vertical retorts which will produce a high calorific value in the gas, with a low volatile content in the coke. An investigation has also been carried out on the possibility of enriching the gas produced in vertical retorts with high rates of steaming, by the injection of oil into the retorts; this has led to some very interesting results, and indicates a method by which the gas made from these retorts can be increased some 15 per cent or more while keeping the calorific value constant.

The results of all the above have been published and have been of considerable value to the carbonizing industries. In the course of the work alterations have been made to the heat insulation of the setting, notably the replacement of the cast iron linings and shutters of the sight holes by fire clay linings and plugs. The result was a very striking reduction in the heat lost from the setting, amounting to over four therms* per ton carbonized. The Station retorts have double the normal number of sight boxes, but the figures illustrate forcibly the necessity for reducing to a minimum the amount of metal exposed at the same time to the heating effect of the combustion chambers and the cooling effect of the external atmosphere.

Before these retorts were shut down as a result of the present coal stoppage, expermients were in progress to determine the effect of increasing the normal throughput. It has been found possible, at any rate with a suitable and graded coal, to double the throughput of the retorts with the result that the coke is more free burning, the yield of tar per ton of coal is increased, the gas yield per ton of coal is reduced, but the yield per retort is increased. These preliminary experiments suggest interesting possibilities, but the investigations have

*One Therm is 100,000 British thermal units.

not yet proceeded far enough for their value to be estimated or the characteristics of the coke and tar to be properly determined.

The results given in the following table may, however, be of interest.

Throughput per retort per day	tons.	2.50	5.02
Duration of test	hours.	72.0	96.0
COAL.			
Total carbonized	tons.	30.0	80.3
Moisture in coal as charged	per cent.	0.7	2.3
STEAM.			
Rate in lb. per hour		187	473
As per cent of coal		20.05	25.24
COKE.			
Over 7/8"	cwts.	12.04	11.6
Volatile matter	per cent.	2.42	3.0
Through 7/8"	cwts.	1.23	2.9
Volatile matter	per cent.	—	12.8
GAS.			
Yield per retort per day	cu. ft.	52,010	60,170
	therms.	244.0	342.9
Yield per ton of coal	cu. ft.	20,810	12,010
	therms.	97.6	68.44
Calorific value. B.Th.U. per	cu. ft.	469	570
Specific gravity (air = 1)		0.424	0.410
TAR (dry).			
Yield per ton of coal	gals.	13.35	15.80
Specific gravity at 15°C		1.100	1.088
AMMONIUM SULPHATE.			
Yield per ton of coal	lb.	22.2	25.45
CARBONIZING TEMPERATURE.			
Mean of combustion chambers	°C.	1,260	1,260
FUEL GAS.			
Fuel Gas per hour	cu. ft.	6,010	7,240
	therms.	17.2	21.4
Fuel gas per therm of coal gas made	therms.	0.42	0.37

In the above, 1 ton = 2240 (British Ton)
1 gal. = 10 lb. water

Remembering that a "Therm" is 100,000 British Thermal Units, the gas yields and calorific values are given for gas at 60° F. and 30 inches of mercury, the gallon is the Imperial gallon, being the volume

of 10 lb. of water. The coal used was Mitchell Main Gas Nuts, a sized and washed coal. The rated throughput of each retort was 2.5 tons per day.

The experience and data obtained from these vertical retorts has proved so valuable that it was decided to erect a setting of horizontal retorts (capacity 10 tons a day) to gain similar data in connection with this type, which is also largely in use in the gas industry. Before doing so a large number of gas engineers were consulted and, although such retorts have been in use for many years the opinion was practically unanimous that many useful investigations could be carried out and many suggestions were made dealing with details of the research. The retorts were only ready for work in January last, and are now only working intermittently because of the coal stoppage. Like the vertical retorts they will also be used for testing the behaviour of selected coals in connection with the work of the Survey.

Low Temperature Carbonization

The problem of carbonizing coal at temperatures of about 600°C. (say 1100°F.) has attracted much attention during recent years. The possibility of obtaining by this means liquid fuels from coal, and at the same time a smokeless solid fuel, makes the process particularly attractive in Great Britain where natural oils do not exist, and where open grates are so largely used for domestic heating. The problem may be looked at from several aspects, for example, it may be that of finding a commercial outlet for some variety or grade of coal for which there is at present little demand. The Fuel Research Board, however, while not excluding other views, must consider the problem on the supposition that a successful solution from the national point of view will result in carbonization products being used for domestic purposes almost to the exclusion of raw bituminous coal. In a normal year some 35 to 40 million tons of bituminous coal are used in this way in Great Britain, and this is among the more highly priced varieties of coal actually mined. If this coal is to be carbonized, it means that a high priced raw material is used, and as the coke commands little, if any, higher price than that of the raw coal, there is then no question of converting a low priced coal into a higher priced coke. If, on the other it were possible to use large quantities of the lower priced coal, the product will displace some of the high priced coal on the market, and

the relative pit head prices of the different grades of coal will of necessity be altered. It follows that the carbonization costs must be kept very low if any profit is to be made from the process carried out on a really national scale.

On the technical side the requirements vary according to local conditions, the type of coal available, the use to be made of the coke, and the markets for the tar and gas. It would appear definite that the maximum tar yields can only be obtained when the volatiles given off from the coal are rapidly removed from the retort. If the vapors pass through a bulk of coal or coke, or pass along the hot sides of the retort, condensation or decomposition takes place. Free passage of the vapors would seem essential, and a sweeping action by gas appears to aid the production and removal of the tar. On the other hand if permanent gases are used for sweeping, especially if they also provide the heat for carbonization, the amount of gas to be dealt with by the condenser is increased, and larger condensers, working probably to a lower temperature, are necessary to recover the tar. If steam be used for this purpose the cost of the steam may become serious.

Work on carbonization of coal at 'low' temperatures, has proceeded steadily at the Fuel Research Station since it was completed in 1919. Much experience and information has been gained, and published, and the results of experience, which cannot all be included in published reports, are placed freely at the disposal of all serious workers who approach the Director. The Director is in close touch with most, if not all, of those working on any considerable scale on this problem in Great Britain, and with many elsewhere. The first low temperature retorts erected at the Fuel Research Station were of a frankly experimental type of horizontal externally heated steel retort, and were used to gain experience of the behaviour of different types of coals and of blends of coal. They produced fairly good yields of tar, and very satisfactory coke, but the labour involved in the coal handling was such as to make them definitely uncommercial, as indeed was expected. It is, however, interesting to note that these retorts, of mild steel, have been in continuous use for nearly seven years, and the metal is in perfect condition. They have, however, not been heated above 600°C except on one or two occasions. These retorts are in continuous use as a standard of comparison with other retorts, and in producing

gas and tar under definite and reproducible conditions so that the effect, on the character of the tar, of various temperature conditions in the retort can be investigated. Low temperature tars differ from ordinary tar, and but little is yet known of their characteristics. Their properties are however being actively investigated both at the Fuel Research Station and at the Chemical Research Laboratory at Teddington.

Larger scale work at the Fuel Research Station has been confined to obtaining data and to attempts to develop a system of carbonization which will produce a free burning smokeless lump fuel suitable for ordinary domestic purposes and at the same time a reasonable supply of tar from which motor spirit and fuel oil can be obtained; systems already being developed by private firms or individuals have not been experimented with at the Station. The first efforts made were to develop the small horizontal retorts into a commercial design, but these were abandoned owing to the distortion of moving metal parts when maintained continuously at temperatures of about 600°C (dull red heat). A method was next tried of briquetting a suitable blend of coals without a binder; Messrs. Sutcliffe and Evans have shown that this is possible with certain coals using a pressure of some 10 tons per square inch in the briquetting process. Laboratory experiments at the Station indicated that lower pressure could be used if the coal was heated to about 250°C before briquetting. The intention in both cases was to carbonize the briquettes in simple retorts, those used at the Fuel Research Station being vertical and of cast iron similar to those used in the Scottish Shale Industry. Many difficulties were experienced in making robust briquettes on a commercial scale with heated coal without added binder and the experiments were finally abandoned. At the same time the experiments showed that briquettes could be carbonized satisfactorily in retorts of the type suggested. The briquetting of suitable blends of coal before carbonizing would appear to hold out some prospects of success provided a suitable binder can be found at a sufficiently low price The binder usually employed in the manufacture of 'patent' fuel is pitch, which is not available in sufficient quantities and at a price low enough for its use for this purpose on a really national scale. Binders of various types can be made from straw and other waste vegetable products by fermentation processes, and investigations

are in progress both by private firms and by the Fuel Research Division to ascertain whether this, or a similar process, may lead to a solution of this problem.

Experiments have also been made with these retorts using blended coals without pre-briquetting. A marked degree of success has been obtained inasmuch as these retorts have now been worked for about two years producing satisfactory coke and tar, but the proportion of small coke made is rather high.

The latest setting to be erected is however a great improvement upon the one referred to above. It contains two simple cast iron vertical retorts, each 21 ft. high, the internal dimensions being 7 in. by 6 ft. 6 in. at the top, tapering to 11 in. by 6 ft. 10 in. at the bottom. These are enclosed in a simple brick setting and heated by gas, either coal gas or blue water gas being used. Although producer gas would probably be used in practice it is not used in the experimental retorts on account of the necessity for accurate measurement of the amount of heat supplied to the setting. It has been found that these retorts work excellently with a sized non-swelling coal, giving good tar yields, and a robust easy burning coke without an undue proportion of breeze. It has also been found that easy working and good yields can be obtained from a sized or screened coal of the swelling variety, but that if fine coal is charged to the retorts, or "run of mine" coal containing fine coal, the tar yield falls off considerably, and the throughput of the setting is reduced. The throughput of coal under the best conditions is 7 to 8 tons a day for the setting, and the temperature of the wall of the retort is kept as close as possible to 625° C. (1157° F.), care being taken to prevent local overheating. The setting in question has been under heat since December, 1925. The method of working is to run the coke extractor for a few minutes at regular intervals of 1 or 2 hours, thus dropping the level of the coke in the retort which is then filled up with coal, and left quiescent until the next charging period. Steam amounting to 10 to 20 per cent of the weight of coal is admitted to the base of the retorts.

The swelling coal which has been satisfactorily carbonized in this manner, has been in store for some months, and may have had its properties modified. The experiments will be repeated with freshly mined coal as soon as this becomes available. Briquettes formed from

the fines screened out of the coal can also be carbonized in these retorts.

Tests of Low Temperature Carbonizing Plant

In order that accurate information should be made available on the results obtained by other workers on the problem of low temperature carbonization and their claims thoroughly verified, the Department has undertaken to test full-size unit plants for low temperature carbonization of coal without charge for the services of its staff, the plants being worked by the owners under test conditions. Two reports have been published, and two more are now in the printer's hands.

These reports deal with the following plants:

(1) Low Temperature Carbonization, Ltd., retorts of the "Parker" type, with a throughput of 50 long tons a day. They produced the yields claimed, and a good lump coke. The heating arrangements were uneconomical, and could be much improved, the temperature control was faulty and the retorts are not now in use.

(2) The Midland Coal Products, Ltd., plant with a throughput of 50 long tons a day. This plant works with briquettes made from a washed slack, both air and steam are passed into the lower portion of the retort, which acts to some extent as a producer, the heat for the carbonization being obtained by the combustion of some of the briquettes in the retort. The gas made is of low calorific value and suitable only for use on the spot as fuel gas or for internal combustion engines, not for general distribution. The coke contains less volatile matter than ordinary "low temperature" coke and is less free burning; it is suitable for use in stoves. The plant gave the yields and throughput claimed and is still working on the Colwick Estate, near Nottingham, the gas being used to supply the power for the industries established on that estate.

(3) The "Fusion" retort. The retort is a rotary externally heated one with internal agitation of the coal. The test was made on cannel coal, and gave a good yield of tar and gas (nearly 80% of the "assay" yield). The throughput during this test was about 3½ long tons a day. The coke was too small in size for use except by briquetting or as a pulverized fuel. The experimental plant is still being developed by the owners with a view to extending the range of raw material for which it is suitable, and a working plant is in course of erection at a colliery.

(4) The "Freeman" retort of the British Oil and Fuel Conserva-

tion, Ltd. This retort is again of the type where the coal is turned over during carbonization and is externally heated. A special feature is the rapid removal of the gas and tar vapors. The retorts failed to run for a sufficient period to obtain a satisfactory test, but were taken over and improved in various details by the Fuel Research staff, after which several satisfactory tests were obtained. Only weakly coking coals were used, and the coke was too small for domestic use and would have to be briquetted or pulverized. The retort failed to deal with more strongly coking coals, but it is possible that modification may enable at any rate medium coking coals to be dealt with. The tar produced showed little signs of cracking, and the yield was higher than has been observed by the Fuel Research staff in any other types of retort, being over 80% of the "assay" yield.

It may be stated that no test is considered satisfactory unless the plant has worked steadily under test conditions for several days, and unless the material measured into the system agrees with the measured products leaving the system within about 1 per cent. The "assay" apparatus mentioned above was developed by Gray and King some years ago, and has been in constant use ever since, as the best available laboratory means of testing the coking qualities of a coal, and its probable yields when subjected to carbonization, especially low temperature carbonization. The yields of tar are always greater in the "assay" apparatus than in a full scale plant, and a comparison of the two yields, using the same coal, forms a convenient method of estimating the efficiency of a plant for the production of tar.

It is unfortunate that some promoters of low temperature carbonization systems do not appear to realize this scale effect, and quote figures for yields which are obtained in the laboratory as if they had been obtained on a plant of commercial size. In some cases the necessity for steady continuous running is also overlooked. It is only after a plant has been running steadily for months that a true estimate of its technical possibilities can be obtained, and proof of satisfactory commercial working can only be obtained by steady continuous working for some years.

The Production of Oil by Methods Other Than Carbonization

There are other methods of obtaining liquid fuels from coal than that of low temperature carbonization. Amongst which may be men-

tioned the hydrogenation of coal, by a process due to Dr. Bergius, and the synthetic production of alcohols and other hydrocarbons from water gas by Patart, Fischer and others.

The Bergius process consists in subjecting powdered coal, mixed into a paste with heavy oil, to pressures of over 150 atmospheres and temperatures of about 400°C. in the presence of hydrogen. Small scale experiments at the Fuel Research Station have shown that by this means a much higher yield of oils is obtainable from suitable coals than by any known process of carbonization, even allowing for the coal expended on the power and heating requirements of the process. A strong British Syndicate has an option on the rights of the process for the British Empire and is conducting experiments in conjunction with Dr. Bergius to ascertain the possibilities of the process on a commercial scale. The technical difficulties of working at the temperatures and pressures involved are obviously great. In view of the great importance to Great Britain of any process which will assist in increasing the oil supply, an agreement has been entered into with the British Syndicate, Dr. Bergius, and the interests now controlling the rights in the process. Under this agreement the Department contributes towards the cost of an experimental program laid down by a joint committee on which they are represented and in return obtains full information as to all results and the right to have a representative present at any time. An intermediate scale continuously working plant is also being installed at the Fuel Research Station for our own experimental use.

Miscellaneous Work

Other work at the Fuel Research Station has dealt with tests on petrol mixtures and producer gas for internal combustion engines, with the testing of boiler house instruments, of recording gas calorimeters, and the development of methods of analysis of gas and coal. A number of special laboratory investigations are in hand. Among these may be mentioned the investigation of melting point of coal ash which is being carried out in co-operation with the Bureau of Mines, the temperature of initial decomposition of coal, the reactivity of coke—this is of importance to the Iron and Steel industry, and is being investigated in conjunction with the National Federation of Iron and Steel Manufacturers.

At the request of the Board of Trade an investigation is being

made into the spontaneous combustion of coal on board ship, and many vessels in which such fires have occurred have been inspected by a member of the staff in company with the Board of Trade inspector.

At the present time a full scale coal purification plant is being erected at the Fuel Research Station, and such types of plant are being installed as will embody the more important of the various principles used. This has a two-fold object, to study the principles involved with a view to improving methods available, and to determine, in connection with the Survey, the most suitable method of treating individual coals.

Apart from work at the Fuel Research Station, and that directly connected with the Survey, general investigations have been carried out on the production of power alcohol, and several memoranda published. Work is being carried on for the Department at the Royal Naval Cordite Factory, Holton Heath, on the production of alcohol from cellulose materials.

Work has been carried out by Dr. Margaret Fisherden on various problems connected with Domestic Heating, and this is being continued in collaboration with the Building Research Division of the Department, at their new research station near Watford.

Assistance is given to various outside individuals or organizations for special researches of interest; these include a payment to the Lomax Palaeobotanical Laboratory for making of thin sections of coal and their microscopic study; assistance to Mr. Kemp for the study of coal by X-ray methods; to Mr. Seyler for a study of the micro-structure of coal by methods he has developed; to Professor Bone for the study of the constitution of coal and (in conjunction with the National Federation of Iron and Steel Manufacturers) for the study of the reactions taking place in blast furnaces. Assistance is also given to Professor Cobb to enable him to pursue fundamental work on several problems of direct interest to the carbonization industries.

The possibilities of peat utilization have been examined, and Professor Pierce Purcell has visited Canada and the Continent of Europe to study the progress made there in the mechanical winning of peat. A full report was published in 1923, and brings out very clearly the difficulties in working peat bogs on a large scale in Great Britain, and the unlikelihood of peat being, under present

conditions, a serious competitor with coal, except in restricted areas with a comparatively small demand.

Close touch is kept with other bodies working on allied problems. The Director of Fuel Research is an assessor to the Safety in Mines Research Board, and their Director of Research, Professor R. V. Wheeler is a member of the Fuel Research Board. The Director of Fuel Research is a member of the Fuel Economy Committee of the National Federation of Iron and Steel Manufacturers, and of the Council of the Colliery Owners Research Association, and of several technical committees of the Institution of Civil Engineers, the Institution of Mechanical Engineers, the British Engineering Standards Association, as well as the Inter-departmental Committee on Petroleum and the Advisory Committee for Coal and the Coal Industry. He also served as a technical assessor to the recent Royal Commission on the coal industry, 1925-1926.

It is impossible in this brief survey to deal with all the activities in Great Britain, or even of those of the Fuel Research Division but it is hoped that it will give a general idea of the work in hand. It is even more impossible to form a reliable estimate of the monetary value of the results achieved. It is not to be expected that every investigation carried out will lead to results of practical importance, indeed were the knowledge available which would ensure this, it would in many cases be unnecessary to carry out any research at all. Investigations which have apparently given no practical result may eventually prove important, and even if they do not, they may still be of value in preventing useless expenditures by others in exploring avenues which have already been investigated and proved sterile.

The value of the work of the Physical and Chemical Survey of the National Coal Resources is cumulative, the full value can only appear slowly as the work proceeds, but results of immediate importance have already been obtained. The savings to the gas industry resulting from introduction of the "therm" system of charging for gas and the resulting freedom from restrictions now no longer necessary, together with the investigations into gas manufacture showing how this freedom can best be used, are incalculable, but large, and owing to the statutes which regulate the finances of all statutory gas undertakings, the bulk of the saving is automatically passed on to the consumer.

The aim of the work on low temperature carbonization is to answer the question "Will it be possible to establish on sound industrial lines a new industry based on the carbonization of the tens of millions of tons of coal per annum which are at present being consumed in the raw state?" The answer may be an unconditional affirmative in which case the benefits to the Nation will be very many times greater than the cost of the whole Research Department, or it may be a conditional affirmative or a definite negative, in which cases the benefits will still be great as it will prevent much unavailing expenditure by firms and individuals.

DISCUSSION

S. A. TAYLOR.* This discussion of Mr. Campbell's paper was prepared before hearing the paper read or having an opportunity to read it.

In this country most of the people who have investigated the quantity of our fuel reserves will have, of necessity, to know more or less of what Mr. Campbell has given us in regard to this subject, for the reason that he, above all others connected with the United States Geological Survey, has intimately studied our coal resources and has published a great amount of information on this subject. Indeed, I know that what Mr. Campbell states as to our resources of coal is taken without any general reservation, and consequently as to the quantity of our coal supply I will not attempt to say very much. I would only like to say that I can remember reading a statement in 1876, our centennial year, to the effect that the coal supply of this country, would last about one hundred years.

About two months ago the geologist of the Colorado Fuel and Iron Company is reported to have said that now in Colorado alone the amount of coal known is sufficient to supply the United States with 600,000,000 tons annually for one hundred years.

I mention this to show that in the last fifty years, although we have produced approximately 15,000,000,000 tons of coal, we have now many times as much coal known to our geologists in this country as we knew existed fifty years ago, and we feel sure that even though we know very nearly all the expected coal fields in this country today, yet no doubt we will still continue to find other seams of coal which will extend the quantity of our reserve.

As to the production and consumption of coal in this country there are some very interesting facts that may be brought out from a study of our coal statistics, some of which I will mention.

The statistics of coal production prepared by the United States Geological Survey show that from 1850 to 1910 the production of coal

*President, American Institute of Mining and Metallurgical Engineers.

practically doubled every ten years, at an average rate of increase of 10% per annum. From 1910 to 1925 this same production was only at the rate of approximately two percent per annum.

This apparent falling off of production calls for some explanation, in view of the fact that the power consumption per capita had increased slightly during this period. Investigation of this condition reveals the following situation as regards the savings and displacement of coal as fuel:

The savings in the use of coal through the medium of central station power plants, allowing a saving of three pounds of coal per kilowatt hour, was in 1925 approximately 100,000,000 tons.

The savings by the use of coal gas and coal tar from the by-product coking plants amounted to approximately 50,000,000 tons in 1925.

The statistics showing the savings due to the economies of coal by the railroads of the United States were somewhat difficult to secure but from the best information I could secure it amounted to approximately 30,000,000 tons in 1925.

Then again the amount of coal displaced by oil for fuel in 1925, counting 3½ barrels of oil to the ton of coal, equalled approximately 200,000,000 tons.

There were some other sources of power which displaced coal, but these were the large economies and sufficient, with the water powers, to account for the apparent falling off of coal consumption in this country.

I should like to mention a few observations on the quality and distribution of coal which may be of some interest at least to those who are not familiar with conditions in our country.

An examination of a geological map of the United States will reveal the coal fields as located in the eastern section of the country in an area approximately parallel with the sea coast or rather parallel to the crest of the Appalachian Mountain range. Then the great area of the mid-continental basins, as we go west, are encountered. Still further west in the Rocky Mountain section we meet other great coal areas and some in the state of Washington—until now out of the forty-eight states in the Union we have some twenty-eight states which rank as coal producing states, with some other states which in the future will be added to this list.

The detail study of these various fields of coal reveal some very interesting facts; for instance, take the fields known as the Appalachian, in which the coal beds were laid down, as formed long before the crust of the earth cooled to the extent of forming the breaks or upthrows of the mountains which left the coal in the various localities, approaching the breaks, of a quite different pitch or angle of inclination from the horizontal planes, at which they were formed. These differ from very steep slopes near the mountains, in gradually decreasing steepness to

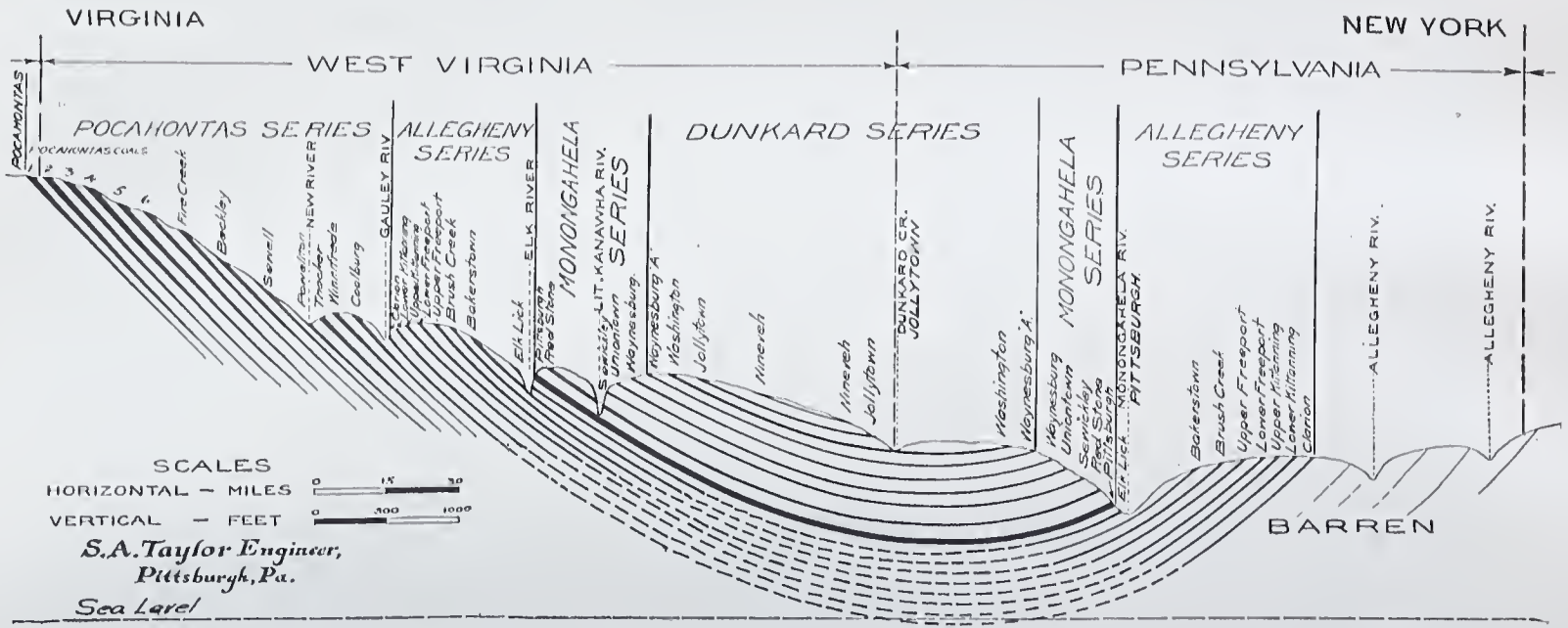

FIG. 1. CROSS-SECTION OF APPALACHIAN COAL FIELDS

an almost horizontal plane in the fields farthest away from the centre of the disturbed area.

The coal beds in the mid-continent fields are practically horizontal and in the Rocky Mountain district to the west we find the angles of inclination are generally just reversed from those of the eastern section.

There is another condition which exists in our eastern fields worthy of note, that the coal seams, say in Ohio where they are comparatively level, have a general dip to the south of about twenty-five to thirty feet to the mile.

Again in following the strata from some point as for instance here in Pittsburgh down in a south and slightly easterly direction the measures thicken to such an extent that many of the seams which in Pennsylvania are very thin have thickened to such an extent that in West Virginia they become seams of a workable thickness. I made a cross section of the Appalachian fields, which passes from Pocahontas, Va., through Charleston, W. Va., Fig. 1., and near to Pittsburgh which intersects all the seams of coal found in this section of the country and it may be interesting to note that this cross section, located as stated, is the only location where this is possible. In this cross section I have used, in some of the geological series, only the coal seams which we encounter in Pennsylvania.

In regard to the quality of coal in the United States we have coals of almost every stage of age and hardness from peat to anthracite coal. and from low moisture, low ash, low sulphur, low phosphorous, low volatile carbon to coal containing these elements up to high percentages and then a variation in all these constituents. To discuss these chemical constituents in their entirety and completely, time would not permit even if I were competent to do so, but the volatile carbon and moisture are very clearly controlled by the location of the various coal beds with reference to the main upthrows or where the breaks in the crust of the earth took place in the cooling and settling process. The parts of the coal seams which were nearest to the main breaks, which caused the mountain ranges, came into contact with the heat generated by said upthrows until the volatile carbon and moisture were practically all consumed, as we find in the eastern Pennsylvania anthracite coals, and in the coals known as the "low volatile" in which a part of the volatile carbon has been consumed in the heat generated as above stated. This condition gradually diminishes as we approach the mid continent fields where they have been practically undisturbed and hold their high moisture and volatile carbon contents practically in the natural condition as laid down. Continuing to the Rocky Mountain fields we find the same reversed conditions as we approach the disturbed areas.

We now know quite accurately the chemical analyses of the coals in the various locations, both approximate analyses and ultimate analyses, so that when we want a coal for some specific purpose which con-

tains a high content of some special component, we can usually locate the desired coal without much trouble.

Remarks on Dr. C. H. Lander's Paper

Not having had an opportunity to read Dr. Lander's paper and not being sufficiently conversant with what message he would bring us on this occasion I will, not attempt any discussion of the paper but use the time allotted to me in stating a few of the things that have been accomplished in various matters which either directly or indirectly apply to bituminous coal.

If we would describe a circle using as a center the place in which we are meeting today, with a radius of five hundred miles it would include an area in which would be located sixty (60%) percent of the population of the United States, and approximately fifty (50%) percent of the population of Canada.

Pittsburgh, the center of this area, is the greatest producing tonnage area of the world, and is accessable to most of the population in the large cities within the above described circle by a night or day ride to Pittsburgh.

The supremacy of Pittsburgh as to tonnage production is largely due to the cheap raw materials used in manufacturing steel, iron, machinery and other articles of commerce.

There has probably not been any one thing which has added to this situation as much as coal. Near the city was found to exist the great Pittsburgh coal seam, which was well adapted for use as fuel and the production of gas needed in the industries.

At Murraysville, within fifteen miles, in an air line, from this place in 1878 natural gas in large quantity was struck, in a sand rock strata, at a depth below the surface of about 1300 feet. This gas was permitted to blow off and burn until about 1882-1883 when our honored townsman and great inventor, Mr. George Westinghouse, designed a method of using it both for domestic and manufacturing use and for piping it into Pittsburgh to the mills and towns in this locality. This gas almost completely took the place of coal for domestic and almost all other uses, except to operate locomotives on railroads, for a number of years. From that day to the present a large part of the citizens of this community have used this natural gas, the composition of which is practically all methane.

The B.t.u. content of the natural gas from this field is very nearly 800 B.t.u. per cubic foot. The result is that this has become the standard for natural gas to be sold in this state. Natural gas was also found in Ohio to some extent, and in West Virginia there was a great quantity of it found. Most of the West Virginia gas was much higher in B.t.u.'s than Pennsylvania gas, and a large part of it contained from 1100 B.t.u. to 1200 B.t.u.

The purpose of mentioning this is to show the possibilities of a much extended supply of gas for this district as follows.

Studies have been made with reference to the location of gas producing plants in Pennsylvania and West Virginia, at places where the pipe lines, through which this gas is brought to this district, and the high grade coal are in such position that coal can be furnished to gas plants constructed at the mines and the resultant coal gas of about 600 B.t.u. can be mixed with the natural gas of higher B.t.u. content and thus furnish a gas which will comply with the requirements of the Public Service Commission of the State of Pennsylvania. There are a number of places where gas plants can be located, and thus the supply of gas to this community may be guaranteed for many years to come. This will also serve to lengthen the life of these gas lines and appurtinances, which from a financial standpoint will be very desirable.

The Pittsburgh district has for many years been used to manufactured gas for lighting purposes and for use in regenerative furnaces. This manufactured gas, especially that used for lighting purposes, had to be washed. Through this washing process the coal tars were recovered, while in the early days the recovery of dyes, medicines, etc., from this coal tar was limited to very few items, as the science of chemistry had not been advanced far enough in this country to permit of the recovery of very much of the wealth of the contents of coal gas.

To the advancement of chemistry perhaps more than any other science we owe the great knowledge which has been acquired as to the by-products of coal and their uses, which has become of such immense value to this country.

Most all of this knowledge has been obtained in the last fifty years, during which time chemists and research men, in various lines of science, have been working. Chemistry for instance in 1875 had 41 elements, some of which were very rare, while today the number of elements has been increased to 92. During this same period the known constituents of coal have increased from about 250 items until today, counting all the various things that can be made from coal, we have over 1,000 items. The value of a ton of coal when divided into all its constituent and marketable elements runs well over $2,000.00 a ton. I do not have the items of cost to produce this $2,000.00 worth of ingredients, and thus cannot determine whether the banker would consider it a profitable investment to embark in such an enterprise from a commercial standpoint. There has been a great deal of research done on other lines of industry, much of which revert back to coal and coal tar products before they proceed very far into the lines in which they started out to investigate.

The research work done in the laboratories of some of the large manufacturing companies of this country as well as those of institutions of learning and foundations for the advancement of science have discovered many things in the way of medicine, anesthetics, dyes, and

materials used in the manufacture of various commodities which have been derived from coal, and no doubt there is much ground yet to be investigated, which will be equally prolific of results.

The investigations in this country are usually along the lines of things that are needed, rather than to determine the things that can be secured and then to work out the combinations in which they can be used. When this latter method of research is carried out there is no doubt that coal will be found to contain many other constituents which will prove valuable.

We have also in this country, made great strides in the way of economies in the burning of coal, until today we are recovering a great deal more of the fuel values of coal than was possible fifteen or twenty years ago. In many places powdered coal is used to a great advantage in the reduction of smoke, but this has, in many places, brought into existence another nuisance in the form of a fine ash which, thrown out into the atmosphere, affects the clothing to such an extent that the laundry business of the country has been greatly increased; consequently the public pays some part of this saving in another way.

For the general information of those whose knowledge is limited along this line, it would be well worth while to read the book written by Hugh Farrell entitled "What Price Progress," recently published by Putnams & Son, in which he shows that while in the past this country has been satisfied for the scientists of the old world to do the investigating, and we of this country would buy such rights for manufacturing as we might want; during the last fifteen or twenty years our large manufacturers and several institutions of learning have embarked in research for its scientific and commercial value, which should redound to the great advantage of industry in this country.

In conclusion permit me to say there is yet much ground to cover in the investigation of bituminous coal and we trust that this conference may be a means of bringing about more cooperation to this end.

FRANK M. GENTRY.* It is with a great deal of satisfaction that we have heard a splendid paper this morning from a distinguished English authority, Dr. Lander. For some years I have followed the work of the Fuel Research Board through its technical publications and reports, giving especial attention to low temperature carbonization.

It seems to me particularly fitting that much valuable contributions to the art should emanate from England where Shirley, in 1658, and Clayton, in 1739, discovered that a combustible gas was evolved in the heating of coal. In this connection it is interesting to note that in the early part of the nineteenth century Samuel Clegg was probably the first person to study the coking of coal at low temperature. At that time, however, there was little demand for oil and he turned his atten-

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tion to the use of higher temperatures in order to obtain the then more valuable illuminating gas.

One of the first to recognize that a maximum yield of oil is obtained when carbonaceous materials are distilled at low temperature, was John Perkins, who in 1853 secured a patent for extracting oil from shale. A year later Sparr suggested the coking of coal for oil rather than for gas under reduced pressure. in 1880, Scott-Moncrieff proposed to free the atmosphere from smoke by partially coking the coal before combustion. A period of ten years followed when little or no work seems to have been done on the subject until 1890 when Parker received the first patent on his Coalite process. Sixteen years later, in 1906, Parker received another patent for the introduction of steam to his retort during carbonization.

I have no doubt but that all of the early experimenters before Parker suffered from lack of a keen appreciation of the two difficulties confronting any low temperature process; the mechanical difficulties, resulting from expansion of the charge, and the thermal difficulties, resulting from the low heat transfer coefficient of coal. Parker, I am convinced, was one of the first to recognize and solve the latter. His two patents just mentioned establish two of the principles of heat transfer commonly applied today; the so-called principle of carbonization in thin layers, and the use of steam as a heat transfer medium.

The first work published in the United States, I think, was in 1908, by Prof. Parr, from whom we shall have the pleasure of a paper later in the conference, in connection with his research on the modification of Illinois coal. From then on the low temperature carbonization of coal has made such rapid strides that I am forced to agree with Illingworth, who I believe on one occasion said, that all men are divided into three classes; those who have invented processes, those who have written about processes, and those who know nothing at all about processes of low temperature carbonization. Indeed, I have investigated in the vicinity of a hundred different processes and each month seems to add new ones to the list.

I feel that the International Conference on Bituminous Coal will be instrumental in bringing together from all parts of the world men who are interested in the several phases of coal processing where they may discuss the present state of the art to the end that our coal resources may be conserved through a more efficient utilization than practical economics have warranted in the past. In closing my discussion I congratulate the Carnegie Institute of Technology upon its organization of this conference which, I trust, will be of benefit not only to the coal industry but to industry and nations at large.

PRACTICAL VALUE OF FUNDAMENTAL RESEARCH ON COAL[1]

By A. C. Fieldner
Chief Chemist, United States Bureau of Mines, and Superintendent Pittsburgh Experiment Station

Introduction

Research may be divided into two classes, namely, (1) pure science research, which is conducted solely for the advancement of knowledge without reference to practical applications or industrial development; and (2) industrial research which is usually carried on for direct commercial ends, such as the development or improvement of a process or material. Both types of research are necessary. But great progress in industrial research can not be made without a sound foundation of continued advance in the various fields of pure science. It is true that "cut and try" methods have solved numerous industrial problems, but the aggregate cost of purely empirical experimentation is tremendous. The occasional discovery or invention from such methods is widely heralded, but the thousands of failures are buried in the archives of the investigators.

Fortunately industry has taken a leaf from the textbook of pure science and is, in many instances, conducting research along fundamental lines on their processes and materials. The great electrical companies have followed this research policy for some years. The results have been of outstanding value. A systematic study of metals resulted in the Tungsten filament for the incandescent lamp; and a similar study of the residual gases in the bulb led to the invention of the high efficiency nitrogen filled lamp. The application of science through fundamental research has displaced gas as an illuminant and is making inroads in the cooking field. The superior advantages of electric lighting are obvious, but cooking with electricity has developed in the face of an energy cost of three to six times that of gas for the same number of heat units. Research on oxidation resisting alloys for heating elements; on methods of applying heat; and on heat insulation to prevent radiation losses have overcome this inherent disadvantage and have placed electricity on a competitive

[1]Published with the permission of the Director, U. S. Bureau of Mines.

basis with gas for cooking, provided the consumer will pay a premium for the convenience and cleanliness of electricity.

The mystery of electricity has been a constant challenge to the investigative mind. It has attracted research ability of the highest order including both the researcher in pure science—actuated only by the desire to investigate electrical phenomena and to coordinate them into laws; and the researcher of the engineering type who applies these laws in the design of a giant power generator or a new radio hookup.

Coal, our largest source of electricity, has not had the same appeal to the imagination of the many. Until recent years only a few scattered academic investigators had any curiosity regarding its origin, constitution, and chemical properties. The public generally regarded coal as a necessary evil—a source of light, heat, and power it is true—but nevertheless something to be purchased at the lowest price and burned without regard to the aesthetic and healthful condition of the surroundings. We are still heating our homes by the laborious methods of the last century, whereas lighting, transportation, and refrigeration have progressed tremendously in contriubting to our personal convenience. Fundamental research and its engineering application have been at the bottom of this progress. The same amount of competent research on coal, its combustion and transformation, would have made this conference possible twenty years ago.

Happily a new period has arrived—a period of intensive experimentation and commercial development of new and better methods of utilizing coal. The popularization of the automobile has forced a general appreciation of the form value of fuels; and the inevitable depletion of Nature's fuels of higher form value—namely, petroleum and natural gas—has directed attention to the need for augmenting and eventually replacing these fuels with products derived from coal.

Fundamental Research on Coal Benefits Everybody

Fuel is essential to our modern industrial civilization. A continuation of our present scale of activity can not be conceived after the mineral fuel resources of the earth become exhausted. Therefore, in the interest of posterity we should husband the bountiful but definitely limited fuel reserves. Prodigious waste of this irreplaceable resource must not be countenanced. On the other hand, research on more economical utilization and the prevention of waste should be encouraged by every possible private and pub-

lic means. Such research benefits this and future generations. It is a public welfare problem of the first magnitude.

The United States Government appropriates some 127 million dollars annually in support of the National Department of Agriculture which deals primarily with food and clothing supplies. The mining industry receives less than two million dollars in support of the Bureau of Mines, of which only $154,000 is devoted to fuel testing, and but a small portion of this fund can be devoted to fundamental research.

Research on coal is similar, in many respects, to agricultural research. Fuel and food are primary essentials of life. Coal and agricultural industries lack central organization and coordination; they can not of themselves at the present time carry their own fundamental research as does the electrical industry. Therefore, it is a proper function for the Government, the university, and other publicly supported institutions to carry on such research. The results are basic to the mining, preparation, and transportation of coal; it is needed for solving the industrial problems of the gas, coke, and smokeless fuel manufacturer; it is at the bottom of more efficient combustion and generation of power from coal, and it will open up a new source of raw materials for synthetic products as shown by the recent developments in the manufacture of ammonia, methanol, and liquid motor fuel from coal.

WHAT IS FUNDAMENTAL RESEARCH ON COAL?

Research has been defined as "Systematic investigation of phenomena by the experimental method to discover facts or to coordinate them into laws." Fundamental research as applied to coal is the pursuit and correlation of generic facts which can be formulated into laws or principles dealing with the composition, constitution, and structure of coal in relation to its behavior on oxidation, combustion, carbonization, or other process of transformation or treatment. The following illustrates the difference between specific industrial and fundamental research:

An electric power station is obliged to store a certain quantity of coal to keep a supply on hand for strikes and other contingencies. They know that coals differ with respect to their liability to spontaneous heating. They have a choice of coals from four different mines. The question is, which coal is least subject to spontaneous combustion. If no information is available on these coals the question can only be answered by experiment. They will probably decide to store equal quantities of each of the four coals and observe their behavior over the storage period and

thereafter store only the coal which shows the least heating. They will thus solve their immediate problem, but the solution has not aided them for other coals or other conditions of storage. They have not discovered and correlated any generic facts relating to spontaneous combustion.

Now how does the scientific research laboratory attack this problem? First, the problem is subjected to a theoretical analysis of the known and probable factors involved in spontaneous combustion. As for example the following:

1. Effect of size of coal.
2. Effect of moisture in coal.
3. Effect of pyrite and its distribution in coal.
4. Effect of temperature on rate of oxidation.
5. Effect of rate of air circulation.
6. Effect of the different coal constituents as
   (a) the fusain or mineral charcoal.
   (b) the bright bands or clarain.
   (c) the dull bands or durain.
   (d) the ulmic matter in coal, etc.

Systematic experiments are then conducted to obtain data on these factors. When the work is finished, information is available which may be used generally in connection with the storage of any coal, and the most favorable conditions for coal storage become known. Obviously such fundamental experimentation takes a long time and is beyond the means of the individual storer of coal. But in the long run it is much the cheaper method. In addition, this knowledge is applicable to other coal problems in ways not anticipated by the investigator.

BRITISH RESEARCH PROGRAM ON SPONTANEOUS COMBUSTION

A concrete example of such a research program on spontaneous combustion is the following one, drawn up by the British Safety in Mines Research Board, the Lancashire and Cheshire Coal Research Association, and the Mining Research Department of Birmingham University, England.

The work necessary to determine the causes of spontaneous combustion are divided into two branches according to their character, namely, (a) chemical, and (b) physical. The chemical researches are again subdivided according to the method of investigation employed in

1. The chemical constitution of coal.
2. The oxidation of coal.

3. The chemical effect of extraneous substances, as pyrites, moisture, etc.

THE CHEMICAL CONSTITUTION OF COAL

Obviously the real chemical constitution of various coals, while complicated and difficult to determine, is fundamental in this and other coal problems. It involves an intricate study of the various ingredients, and the various morphological entities, that are contained in coal. It must be carried along broad lines, involving (1) microscopic examination and identification of plant entities; (2) separation of the coal substance into groups by solvent extraction; and (3) treatment of the coal and constituent parts of the coal by methods of destructive distillation, oxidation with reagents, and other chemical reactions. The coal constituents should be correlated as far as possible with plant constituents by subjecting these to similar treatment and comparing the results.

It is self-evident that a complete knowledge of the constitution of our various coals and lignite and of the behavior of these constituents under various conditions of heat treatment will furnish the basis for solving most of the problems in coal technology, whether they be storage, combustion, carbonization, gasification, or conversion to liquid form.

The combustion engineer knows that coals vary greatly in their burning properties on stokers; practical experience has shown him that due to some indefinable physical or chemical properties one coal is satisfactory while another of the same chemical analysis is not. Likewise the coke oven or gas works superintendent must determine by actual trial in his equipment the yield and quality of the carbonization products. We should know enough about coal to answer these questions in advance on the basis of simple laboratory tests. The United States Geological Survey, the Bureau of Mines, and many of the State Geological Surveys have published analyses and calorific values of most of our American coals. These are of great value in the selection of coals for industrial purposes, but they are inadequate for the complete evaluation of coal. They tell us little about their burning properties on a grate, their coking properties in an oven, or the quality and quantity of the gas, coke, and by-product yield. Systematic scientific research is needed on a large scale now that we are beginning to appreciate the industrial possibilities in processing coal with the simultaneous production of valuable by-products.

PETROLEUM INDUSTRY RESEARCH PROGRAM

The petroleum industry recognizing the same need, has within the last year started a program of purely scientific study of the origin and nature of petroleum. This research has been made possible by two grants to the American Petroleum Institute of $250,000 each, from John D. Rockefeller, Sr., and from the Universal Oil Products Co. One hundred thousand dollars a year is to be expended by the Institute in the support of fellowships in universities, research institutes, or Government bureaus.

Some 30 different research projects relating to the geology, physics, and chemistry of petroleum have been recommended by the Central Petroleum Committee of the National Research Council. Work is already under way on a number of these projects. There is little doubt that funds will be forthcoming to continue this program beyond the five years provided for. Leading executives in the industry believe in the value of such research. Frank A. Howard,[2] President of the Standard Development Co., in a paper on "Business View of Petroleum Research," said

"Only so fast as the foundation of general scientific knowledge has been enlarged has it been possible to erect a sound superstructure of industry. Where industrial development proceeds without an adequate foundation of basic knowledge, the structure built up is unnecessarily costly and wasteful of natural resources. I think that American industry as a whole is apt to be tainted with this fault, the petroleum industry not more than others. Pure research in fields bearing even remotely on petroleum and the utilization of its products should be and will be prosecuted more and more extensively. Industrial research and development work will provide its own quota of new knowledge and will build upon this and upon the contributions of pure science and of other arts, first in one direction, perhaps, and then in the opposite direction, as the necessarily short-range view of business permits, but with the result of providing as the years pass an ever widening horizon of basic knowledge transmitted through technical skill into serviceable industrial operations and commercial products."

A PROPOSED RESEARCH PROGRAM FOR COAL

Obviously these remarks apply with even greater force to coal and its products. Coal is a conglomerate of widely different compounds which are derived from vegetable matter laid down in beds similar to the peat deposits of the present age. Differences in the original vegetation, in the method of accumulation, submergence, and subsequent pressure have produced major varieties of coal ranging from the youngest stages of coal formation, as the brown coals and lignites, through the intermediate rank

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2Howard, Frank A., "Business View of Petroleum Research," The Oil and Gas Journal, September 23, 1926, pp. 73, 98-101.

of bituminous coals to the highly metamorphosed semi-anthracite and anthracites. There are many variations in the chemical and physical properties of each variety or rank of coal. The problem is further complicated by the presence of variable amounts of incombustible impurities which produce the ash of coal. These variations have their effect on the use of the coal and its behavior in the processes of combustion, coking, gasification, and liquefaction. Therefore, the building of a broad and sound foundation of pure scientific research on the fundamental properties of coal is of first importance. This research program would center around the origin and constitution of coals and lignite and the relation of constitution and composition to reactions and products. Around this central plan would be grouped scientific studies of the chemical and physical properties of the solid, liquid, and gaseous products of coal. A review of the 31 projects for research in petroleum published in the bulletins of June 30 and October 25, 1926, of the American Petroleum Institute shows that, with but slight modification, 22 of these projects are applicable to research on coal and its products.

Project 2. "Experiments in the artificial carbonization of carbonaceous rocks by geophysical methods," if applied to coal would furnish experimental data on the geologists' theories of the formation of the various ranks of coal from brown coal to anthracite. You will recall that the next speaker (Dr. Bergius) on this afternoon's program produced a synthetic anthracite some years ago by subjecting sawdust to high pressures under suitable conditions of temperature control.

Project 3. "Studies of source rocks in the micro-furnace," would be of great value in determining which of the entities of coal cause coking and yield liquid and gaseous products; such investigation would give information on the behavior of the coal ingredients at various temperatures.

Project 4. "Origin and environment of source sediments," also applies to the origin of coal, through a study of peat, brown coal, and lignite deposits.

Project 5. "Critical study of selected source beds," has its counterpart in the study of coal beds as carried on by White and Thiessen from the viewpoints of the geologist, paleobotanist, and chemist. The Carnegie Institute of Technology and the Bureau of Mines have been conducting such a study on the coal beds of Western Pennsylvania and have published three bulletins to date.

Project 6. "The separation and determination of the chemical constituents of commercial petroleum fractions," applies with equal force to

coal, coke, tar, and gas. The plan proposed for petroleum is also suitable for low temperature tar on which such information is badly needed for the commercial development of such processes.

Project 7. "Catalytic methods applied to petroleum hydrocarbons," is equally applicable to the gaseous and liquid hydrocarbons formed in the distillation of coal, and with coal the work should include carbon monoxide and the complex carbon-hydrogen-oxygen compounds as well. Two of the papers of this conference, namely, "The Industrial Transformation of Bituminous Coal into Organic Technical Products," and "The Synthesis of Petroleum," describe practical results of research on this purely scientific problem.

Project 8. "The effect of electric discharge upon gaseous hydrocarbons," is of even greater interest to the coal processing industry if applied to coal gases which contain hydrogen and carbon monoxide in addition to hydrocarbons.

Project 10. "Analysis by fractional distillation from absorbent materials (charcoal, silica gel, etc.) both of light and heavy members of the hydrocarbon series." This method is of particular value in the examination and evaluation of the rich gases from the low temperature distillation of coal, and also in studies of light oil recovery from coke oven gas.

Project 11. "Analysis of the gradual oxidation prior to ignition of fuels in internal combustion engines, and the relation of such oxidation to detonation," obviously applies to motor fuels made from coal.

Project 13. "Determination of physical properties of petroleum and petroleum products," needs merely the substitution of the word "coal" for "petroleum."

Project 14. "Preparation of pure typical hydrocarbons and a study of their behavior when heated alone and with catalysts;" Project 16, "Isolation and investigation of thermo-labile hydrocarbons present in petroleum;" Project 18, "Non-catalytic thermal decomposition of pure hydrocarbons and related compounds;" Project 19, "A study of the relative rates of reaction of the olefines;" Project 26, on "Determination of the thermal conductivity of gases and its application to the precise analysis of hydrocarbons and other gases;" Project 29, on "The catalytic transformation of unsaturated aliphatic hydrocarbons into corresponding alcohols;" and Project 31, on "The action of sulphuric acid on paraffin hydrocarbons," represent a group of problems that are of fundamental importance in the coal distillation industry, in connection with the gaseous and liquid products. For such application the research would be extended to

include carbon monoxide, hydrogen, and the liquid carbon-hydrogen-oxygen compounds. The possibility of new processes for the production of synthetic chemicals and motor fuels from coal makes these projects of great interest in the utilization of coal.

Project 17, "Isolation and study of the sulphur compounds present in petroleum;" Project 21, "Determination of physical and chemical properties of all types of sulphur compounds present in petroleum;" and Project 28, "A study of the reactions of selected organic sulphur compounds," are of equal need with respect to coal and its products. Powell and others have contributed considerable data on the forms of sulphur in coal, their transformation in carbonization, and the forms in which sulphur appears in coke, gas, and tar. Further work is needed since industry will be faced with the necessity of using coal higher in sulphur, when the available low sulphur coals become depleted.

Project 20. "Isolation and investigation of nitrogen compounds present in petroleum," also applies to coal. Nitrogen is the source of the by-product ammonia used in fertilizers. However, not more than half of the coal nitrogen is so recovered. If we knew more about the forms in which it occurs in coal and the reactions of these nitrogen compounds in carbonizing processes, greater recovery might be obtained.

Project 30. "A study of the metallic constituents of crude petroleum," has its analogue in Dr. Lessing's research on "The Mineral Matter in Coal." This mineral matter is extremely variable in composition, amount and distribution in coal. It affects combustion and the quality of coke produced. Systematic studies are needed on this problem.

Present Status of Fundamental Research on Coal

In emphasizing the need of a research program on coal similar to that now in progress on petroleum, I do not wish to give the impression that little or nothing has been or is now being done in this direction. As a matter of fact, we know more about the constitution of coal than is known about petroleum. We know its origin is from vegetable matter and we have traced the progressive coalification of this vegetable matter through geological history. As early as 1830, plant structures were identified in thin sections of coal examined under the microscope. Recent work with the microscope has shown that all coal, including lignite, brown coal, and anthracites, shows plant structure. So far has the microscopic examination of Pennsylvania coal beds proceeded that the different coal beds can now

be identified, in many instances, by the distinctive appearance of certain spore exines peculiar to the vegetation that made up the individual coal bed.

We know that coal can be divided by treatment with organic solvents into fractions which have different general properties. We can separate the constituents which, when together in the original coal, are responsible for the coking properties. The distillation of coal at low temperatures has provided a means of separating gaseous and liquid primary decomposition products which with further research and large scale mechanical development may lead to a new industry. Scientific research on the effect of hydrogen under pressure and at elevated temperatures promises to furnish a means of obtaining liquid fuel in quantity from coal.

Much of this fundamental research has been done by individual university investigators interested only in the pursuit of knowledge. But in recent years organized group research on coal has been undertaken in a number of countries. Nations have recognized the prime importance of fuel and have encouraged fuel research. In England there is the Fuel Research Station and the Safety in Mines Research Board; in France, the Central Committee of Collieries and the National Association of Research for the treatment of Fuels; in Germany, the Muelheim-Ruhr Institute for Coal Research, the Upper Silesian Institute for Coal Research, and the Institute for Brown Coal Research at Freiberg; and in the United States the National Bureau of Mines and several university groups.

These are typical of the institutions which publish the results of their scientific work, and which in turn furnish the data for industrial research and development by the many industries which are interested in coal and its products. In the aggregate these fundamental research institutions represent but a modest beginning. Their total annual expenditure is small compared with the money lost each year on futile commercial experimentation, that fails because of the lack of fundamental data. The general interest in the fuel problem is shown by the large attendance at this conference. The coal operator, the gas and coke manufacturers, the public utility, in fact everybody is directly concerned with progress as a result of research on coal. Let us, therefore, extend our fullest cooperation to the support of systematic and continuous research on the fundamentals of coal, its uses, and its products, in order to provide a broad foundation that will facilitate the growth of the superstructure of industrial application.

THE TRANSFORMATION OF COAL INTO OIL BY MEANS OF HYDROGENATION.

By Dr. Friederich Bergius
Heidelberg, Germany

For more than a decade attention has been turned in Europe to the problem of making oil out of coal. Europe's oil supply, unlike America's, has become limited. In the days before the great development of the present motor-combustion transportation, Galicia, Rumania and Russia supplied the European demand for oil, and the producers' only problem was to create a market for it.

In the years of the Great War and those following, conditions in Europe were completely changed. Europeans saw with great concern the shutting-off of their oil-supply from other continents because of the enormous growth of domestic consumption at the source, and a future in which they were liable to be shut off entirely.

In the well-informed circle which I am addressing, and in a country in which the statistical control of production and consumption has been so highly developed as it has been in the United States, it is hardly necessary for me to give figures to illustrate these well-known facts. I merely

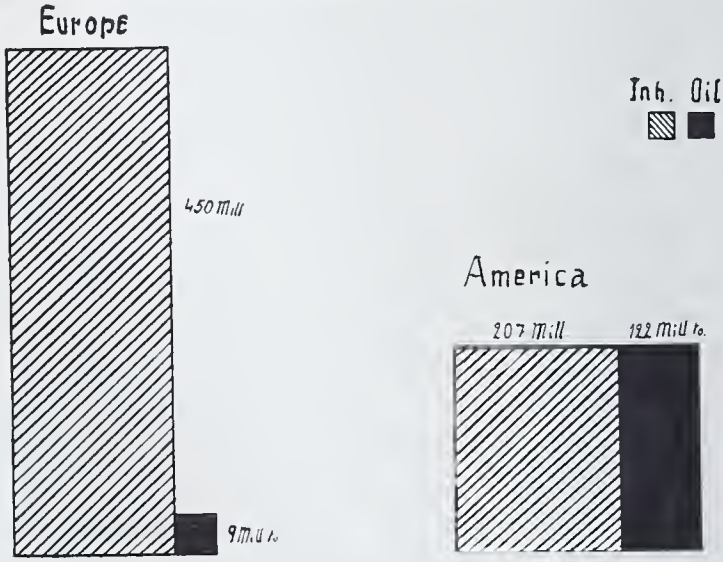

Fig. 1. Relative Oil Supplies

want to point out that America is far better off, in the international picture, than Europe. This fact is shown by Fig. 1. From the situation that exists today, it is easy to understand why the replacement of natural oil by an artificial substitute is one of Europe's most serious industrial and economic problems.

The only raw material that can be used for such an industrial process is coal or a similar carbonaceous material.

Three different lines of work, differing in principle, have been followed in solving this problem. The oldest and most widely discussed in chemical literature is a continuation and perfection of the well-known coal distillation process, usually called low-temperature distillation. The chemical reaction used in gas and coke oven plants for nearly a century was studied more intensively under different physical conditions, and a series of technical means were tested and some of them practically applied.

There is no doubt that, after many errors, some of the processes of low-temperature distillation that have worked out are admirably designed and adequate. In my opinion there is also no doubt that these will play a very important role in making a special kind of coke out of coal, namely, a smokeless fuel, recovering a certain amount of low-temperature tar.

But, as in these processes oil is merely derived as a by-product, it is not likely that the quantity of oil recovered will ever figure in increasing the oil supply of the world to any great extent. Regarding the possibilities of the low-temperature processes, I am inclined to agree with Mr. Henry L. Doherty, who expressed the opinion before the Institute of Politics that the whole American coal production, if treated by low-temperature processes, would contribute only a small quantity to the American gasoline supply. However, the opinion of Mr. Doherty is right only so long as the coal-distillation processes are regarded as the only methods for making oil from coal.

Regarding the first of the three principles, my opinion is that coal distillation at high and low temperatures is important from the standpoint of utilization of coal, but of no big importance from the standpoint of a future oil supply. The development of these processes will depend on the selling of the coke, their chief product.

Before taking up the historically second of the three principles, the question of *direct liquefaction of coal by means of hydrogenation*, the subject upon which you have very kindly invited me to report to you, I want to say something about the third, the synthetical manufacture of

oils out of coal products, which, as well as the low temperature distillation processes, will be discussed before you by more competent men than myself in the course of this conference. But, in order to make clear the principal diffierences between these three lines of work, I think a few words of explanation are necessary.

The basis of chemical oil synthesis, the third of the three methods, is the building up of hydrocarbons from their chemical elements. A direct synthesis of hydrocarbons from carbon and hydrogen is possible but not of interest from the industrial standpoint. At certain temperatures the hydrocarbon methane can be made out of carbon and hydrogen, and at much higher temperatures acetylene and benzol can be formed directly. By using metal carbides liquid hydrocarbons can also be formed. But these reactions are interesting only from a scientific standpoint.

Thirteen years ago a patent application was taken out by the Badische-Anilin-und-Sodafabrik to cover a new reaction for synthesizing hydrocarbon compounds. As a reaction raw material, not the element carbon itself was used, but instead carbon monoxide, which under high-pressure and the presence of certain catalysts, combines with hydrogen to form hydrocarbons and hydrocarbon-oxygen compounds.

From a very thorough study of the catalytic influences of different contact materials, and of the effect of impurities in the gases, the well-known industrial process of making methanol and other alcohols was developed, and the conditions were established which made possible the production of either hydrocarbons or alcohols by the use of this catalytical reaction.

On the basis of this reaction, first described by the Badische-Anilin-und-Sodafabrik, Franz Fischer in Germany, and General Patart and M. Audibert in France, have carried on considerable research and technical work to build up a process for the synthesis of organic compounds and of motor-fuel out of carbon-monoxide and hydrogen.

There is no doubt that, from the chemical and technical standpoint, this synthesis may be carried out successfully. However, it is uncertain if the manufacture of motor-fuel in this way can prove to be an economic success. The fact that the Badische-Anilin-und-Sodafabrik, which discovered the reaction and whose experience in industrial high-pressure work is well known, uses this process only for the production of methanol and high-value alcohols and not for making motor fuel, seem to question the economic possibility of making motor fuel cheap enough by means of this reaction.

A new proposal to carry through this reaction under normal pressure conditions, instead of high, seems to hold no more economic advantage to those who have learned the advantages of high-pressure methods for carrying through chemical processes in which large quantities of gases are used.

The experience gained during years of difficult study in the industry of synthetic ammonia and in developing the coal-liquefaction process, has taught that construction and manipulation of high-pressure apparatus is no longer a problem. But the technical advantage produced by the reduction of gas volumes under high-pressure and the possibility of heat recovery of highly compressed gases are such economy factors that high pressure systems are preferable to normal pressure systems. For such mass-production processes dealing with large quantities of gas are now successfully worked.

Natural coal and lignite are built up from two sorts of chemical compounds, one, the carbonaceous part, which is derived from the cellulose and the lignine part of plants that formed the geological deposits, and the second, the bituminous part, derived from fats, albuminous material, resins, waxes and other accessory material. The carbonaceous material contains hydrogen, carbon and oxygen; the bituminous matter, a higher hydrogen content and a lower oxygen content.

Considering that in a normal bituminous coal the ratio between carbon and hydrogen is about 16 to 1, and in a liquid oil about 8 to 1, it follows that in order to transform coal into oil the hydrogen quantity has to be doubled. Hydrogen being an expensive material, it is important to conserve as much as possible of the original hydrogen content of the coal.

But the distillation-process, as well as the synthetical process, works precisely in the opposite direction. The distillation-process delivers fairly large quantities of free hydrogen out of coal, the synthetical process separates the hydrogen and the carbon completely. In the latter process coal is transformed into coke and coke in turn is transformed into carbon-monoxide, which means that hydrogen is not only separated from carbon but that oxygen is added to carbon. The carbon-oxide is brought into reaction with new, specially manufactured, elementary hydrogen, which is partly consumed for binding the oxygen and partly added to the carbon to establish the proper proportion mentioned before.

From the fact that hydrogen production means coal consumption, or consumption of energy in any other form, and that for making one weight-

unit of hydrogen at least eight weight units of coke are necessary, it is evident that, from the standpoint of conservation of energy, it is most important to conserve the hydrogen bound to the carbon of the coal as much as possible while transforming coal into liquid hydrocarbons.

It is with this point in mind that the direct hydrogenation and liquefaction process of coal has been considered, planned and developed. In the year of 1913, in my laboratory in Hanover, the direct addition of hydrogen to coal was first carried out in collaboration with my assistants, H. Specht and F. Billviller. We called this reaction the *coal liquefaction process*. Using the pre-formed hydro-carbon compounds of the coal, it was the intention to add the lacking quantity of hydrogen necessary for transformation of the coal into oil.

As you may imagine, the so-called invention of coal liquefaction was not accidental, as inventions and discoveries often are. It was the consequence of a long study of the chemical nature of coal, begun three years before. The reaction of coal liquefaction was first determined. My assistants and myself have endeavored since that time to come to a better understanding of what the chemical nature of coal is.

Many chemists believed at that time that coal was merely carbon mixed with some impurities containing hydrogen. The methods of analytical chemistry then in use did not give any clue for making a theoretical picture of the molecular construction of the compounds which form coal. It seemed to me that it might be possible to throw light onto this question by building up a laboratory method which followed the way which nature took in the geological ages for forming coal out of plants.

It is not possible here to give a description of the very complicated research work done for some years in connection with this method. In 1912 I made before the Congress of Applied Chemistry in New York a report on the first results of this research . We proceeded to study the reaction of transforming cellulose and wood into coal by a special method. The synthetical coal produced was very similar to the natural product. By controlling the products and the reaction conditions, I formed an idea of the chemical structure of the chief reaction product, coal. I never published the constitutional formula which I had in mind when carrying out this research, because it was then only an hypothesis for working, and not easy to prove to a chemist as a tenable scientific theory.

But, whether right or wrong, the hypothesis proved to be a very valuable one because it classified coal into a group of chemical compounds, which, under certain conditions, are capable of taking on hydrogen. If

our theory of coal structure was correct, then the addition of hydrogen meant transformation of coal into hydro-carbon molecules and the formation of some amount of water. This was the situation of our research work in the year of 1913.

At this point we were confronted by the question: Could hydrogen be forced into combination with the naturally indifferent coal, and by a method that could be applied practically? With the old laboratory methods,as early as 1869 the great French chemist, Berthelot, could reduce coal and carbon by treating them with hydroiodic acid, making liquid compounds. But this reduction was not suitable for practical purposes and was theoretically different from our idea of adding elementary hydrogen.

At this time, the catalytic hydrogenation of unsaturated compounds was being used in chemical laboratories and in chemical technique, especially in the hydrogenation and hardening of fats, and in the synthetical ammonia industry, then very new. But it was evident that a catalytic process could not be used for material like coal, with the limited knowledge of catalysts at that time. Moreover, hydrogen did not react with coal under normal conditions and at temperatures at which coal was not totally decomposed. We discovered that under certain conditions the effect of catalysts may be replaced by a very high concentration of the reacting gas, and we could realize the reaction by means of hydrogen under very high pressure.[1]

This meant that perhaps the solution of the coal-oil problem was at hand.

I need not say that this study has involved a very complicated research. From the beginning I realized that I had taken on an enormous task. But looking at the oil-supply problem from the European side, the burden was inevitable.

In the laboratory work great difficulties arose as soon as larger quantities were used for the reaction. Our first method no longer produced a solid hydrogen-oil material as a reaction product, but a cokey substance. The reason for this disturbing factor was found to lie in the fact that the hydrogenation reaction produced a large amount of heat, which could only be led off with difficulty from the system of gases and solid material. It was unavoidable, therefore, that superheating occurred by which the reaction temperature was increased to a degree that instead of the hydrogenation reaction, the coal-distillation producing coke began. We could

[1]The effect of special catalyst could be found out in the continuation of the research work.

overcome this new difficulty by carrying out the reaction in presence of a a liquid medium, practically a coal oil, which, suspending the coal, avoids superheating. Fig. 2 and Fig. 3 give an idea of the laboratory apparatus used in the beginning and later.

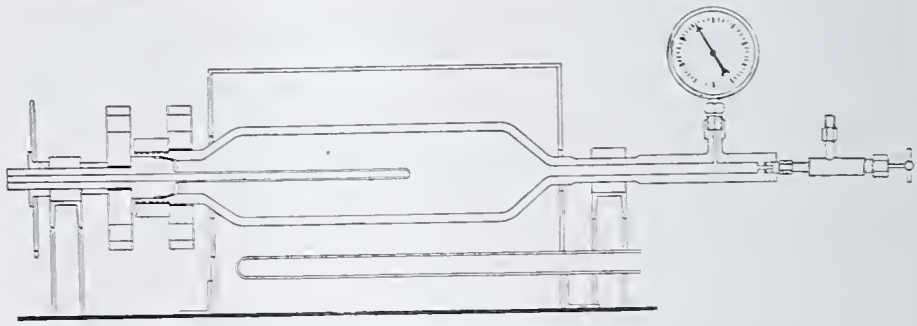

Fig. 2

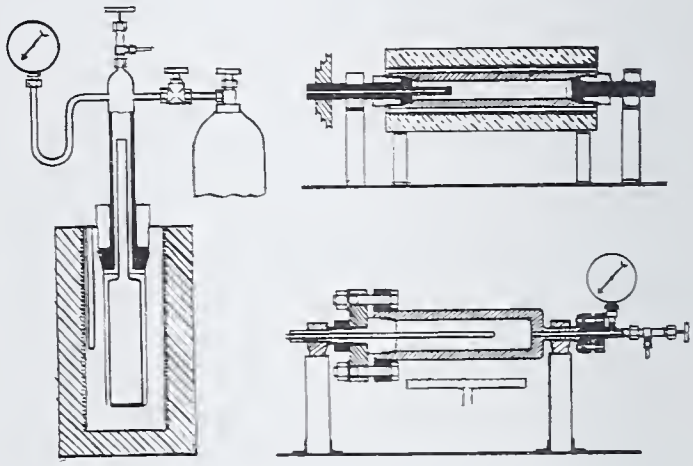

Fig. 3

We realized soon that liquefaction of coal involves more or less a competition between two reactions—the reaction of hydrogen addition to the coal substance, and the reaction of destructive distillation of coal. Within a certain range of temperature the velocity of hydrogenation reaction is greater than the velocity of the coking reaction. At higher temperatures the coking reaction is faster and results finally in the formation of coke instead of oil, even if hydrogen pressure is high and hydrogen is brought into the closest possible contact with the coal.

The hydrogenation of coal begins at relatively low temperatures. Treated for some hours at a temperature of 300-350° C. the product is still solid, but it has taken up a fairly large amount of hydrogen, and is

transformed into a sort of pitch with a fairly high melting point. This product becomes liquid if treatment is continued at a temperature of about 450° C.

From these facts it is readily understood that the coal liquefaction reaction process, regarded from the chemical standpoint, consists of two different reactions: the first, hydrogen addition, and the second, the splitting up of large molecules into smaller ones while new hydrogen is added.

This second reaction involves the very same procedure as the splitting-off of heavy oil residues of tars at low temperatures in the presence of hydrogen under pressure, a process which has been carried through by us on a large scale. In other words, it is a cracking process in which hydrogen is absorbed. By changing the conditions, the relation between gases, light and heavy products can be varied.

From the foregoing you see that coal-liquefaction represents the sum of a complicated system of various chemical reactions to which the laws of normal organic chemistry are not easily applicable.

Hydrogen enters the comparatively large molecular complex. The higher the temperature, the more the larger molecules are broken up into smaller ones, to which the hydrogen is added, thereby changing the unsaturated smaller molecules into saturated ones.

Beginning with methane and extending up to the highest hydrocarbon compounds typical representatives of the aliphatic, aromatic and hydroaromatic series are in the coal liquefaction products, except of course, the

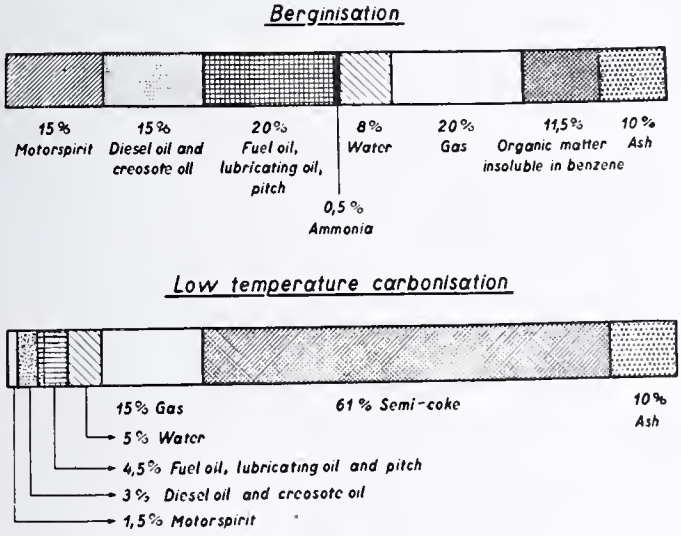
Berginisation
15 % Motorspirit
15 % Diesel oil and creosote oil
20 % Fuel oil, lubricating oil, pitch
8 % Water
0,5 % Ammonia
20 % Gas
11,5 % Organic matter insoluble in benzene
10 % Ash
Low temperature carbonisation
15 % Gas
5 % Water
4,5 % Fuel oil, lubricating oil and pitch
3 % Diesel oil and creosote oil
1,5 % Motorspirit
61 % Semi-coke
10 % Ash

Fig. 4 Yields from Bituminous Gas-Coal
(Calculated on Dry Substance)

Fig. 5. Bituminous Coal and Derived Products
Upper: By Barginisation
Lower: By Low Temperature Carbonization

unsaturated compounds which cannot be formed in the presence of high-pressure hydrogen. Besides these chemical compounds those of phenolic character, chiefly cresol, and ammonia, are among the products. The average output of products from a normal coal is shown in Figs. 4 and 5. Very difficult and complicated research work was necessary to obtain these results, involving extended experiments with high-pressure

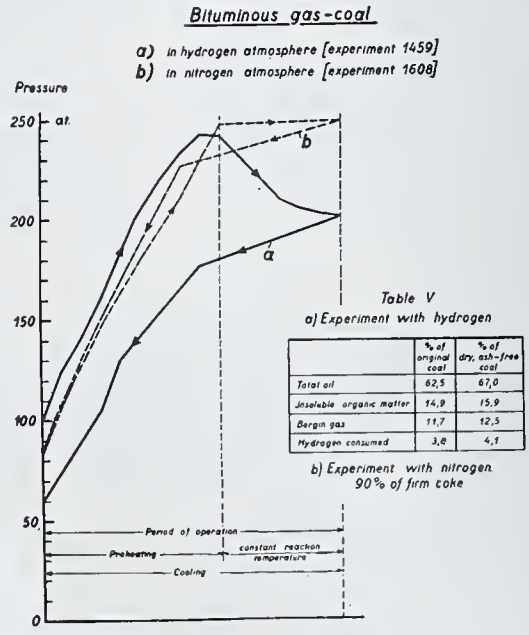

Fig. 6

apparatus, exact heating and temperature control and special analytical methods.

Only a few years ago, after the period in which we had already made thousands of experiments, articles were still being published which denied the possibility of coal-hydrogenation. It is only within a very recent time that the chemical possibility of coal liquefaction has been generally recognized. The opinion was expressed at the time that our coal liquefaction reaction was no more than a low-temperature distillation of special coals. By comparing two simple experiments, made under the very same conditions, one with hydrogen, the other with nitrogen, under pressure, we proved this opinion wrong. You will see the result in Fig. 6.

One of the most important questions of the chemical research work was to find out which quality of coal could be treated by the liquefaction method with best results. A very large number of coals and lignites were studied in thousands of experiments. This study included nearly every sort of coal and lignite, except anthracite, from most parts of the world. Lignites have a little greater reaction velocity and are liquefied more completely than bituminous, leaving only about 10% of untransformed material, depending on the temperature used. About 50% of the nitrogen of the coal is transformed into ammonia. The rest is found in the form of an organic base in the liquid products. The greatest part of the sulphur of the coal is transformed into sulphuretted hydrogen, one of the classes of gases out of which it can be easily recovered. Table I shows how small a part of sulphur goes into the liquid products. The influence of pressure is shown in Tables II and III.

Table III will give you an extract of the experiments, showing how the yield in oil varies from 40 to 70—according to the various sorts of coal. All these calculations are based on the percentage of *weight* of the coal introduced into the apparatus. In other words, one short ton of coal yields 107-185 gallons of oil. These figures are based on normal ash-contain- samples, taken from the pits.

It is often reported that coal-hydrogenation is only applicable to special sorts of coal, but I want to make clear here that only anthracites, the real anthracites, and those coals also which consist chiefly of fusain material, cannot be hydrogenized. However, for any other sort of coal, including lignites, the hydrogenation reaction is applicable. The average output is between 40 and 70% when the ash contained is not higher than

TABLE I

BERGANISATION OF COAL CONTAINING 11.7% SULPHUR

	OUTPUT OF COAL:					
	Up to 230°		230 to °330°		More than 330°	
No.	% Oil	% S	% Oil	% S	% Oil	% S
450	14.9	0.6	19.4	1.4	35.4	1.7
470	16.2	0.4	20.4	0.9	29.5	1.4
480	17.1	0.4	17.9	0.9	26.0	1.4

TABLE II

INFLUENCE OF TIME—TEMP.

Test No.	Temp. °C.	Duration Mins.	Remainder Coal % of pure coal
1221	460°	60	11.5
1229	480°	15	12.6

INFLUENCE OF PRESSURE

Test No.	Initial Pressure Atmosphere (cold)	Remainder Coal % of Pure Coal
1221	100	11.5
1237	75	17.2
1238	50	Formation of Coke

TABLE III

FOREIGN COALS

Coal No.	Test No.	(Proximate Analysis of Dry Coal) Ash	Fixed Carbon	Volatile Matter	Volatile Matter In Pure Coal	Results Oil Yield % of Raw Coal	% of Pure Coal	Remainder Coal % of Raw Coal	% of Pure Coal
101	1457	18.3	48.3	33.4	40.8	48.0	61.0	7.9	10.0
102	1401	6.0	60.5	33.5	35.7	62.2	66.7	8.3	8.9
103a	1464	4.2	60.0	35.8	37.3	51.7	54.3	13.6	14.3
103b	1466	9.8	54.2	36.0	40.0	56.3	65.4	8.0	9.3
104a	1467	5.0	64.0	31.0	32.6	51.0	53.8	17.5	18.4
104b	1469	4.5	63.5	32.0	33.5	49.1	52.3	15.5	16.5
104c	1471	7.5	73.5	19.0	20.5	43.0	46.8	22.2	24.1
105a	1485	5.9	66.5	27.6	29.3	50.0	52.4	11.4	12.4
105b	1472	9.4	65.2	25.4	28.0	47.0	54.6	10.6	12.3
105c	1598	9.5	69.2	21.3	23.5	48.7	55.6	12.9	14.7
106a	1486	11.1	58.0	30.9	34.7	36.6	46.0	24.8	27.8
106b	1537	15.7	54.7	29.6	35.1	50.6	57.5	13.9	15.8
107a	1489	7.4	57.8	34.8	37.6	51.0	58.6	10.3	11.8
107b	1493	12.1	12.1	50.3	37.6	40.7	51.8	17.7	22.6
108a	1496	23.3	45.7	31.0	40.5	38.2	48.8	16.4	21.0
108b	1499	4.0	56.0	40.0	41.7	49.8	51.4	18.2	18.8
109a	1518	5.3	59.5	35.2	37.2	51.5	58.0	13.4	15.1
109b	1514	11.0	56.5	32.5	36.5	57.6	63.0	15.5	16.9
109c	1515	7.9	59.3	32.8	35.6	54.8	61.6	11.0	12.4
110a	1517	4.8	59.0	36.2	38.0	51.8	55.3	17.5	18.7
110b	1521	7.7	63.0	29.3	31.8	56.0	64.0	11.4	13.0
110c	1526	8.0	61.5	30.5	33.0	42.4	47.6	19.3	21.8
111a	1527	11.4	55.4	33.2	37.5	52.2	60.5	14.0	16.2
111b	1530	8.5	53.6	37.9	41.4	50.8	57.0	13.9	15.6
111c	1529	8.4	57.4	34.2	37.4	45.7	54.8	14.6	17.5
112a	1549	11.0	49.5	39.5	44.4	57.2	64.8	13.1	14.8
112b	1552	4.0	56.6	39.4	46.0	57.2	61.2	9.3	9.9
112c	1555	7.1	59.5	33.4	36.0	50.0	54.5	15.7	17.1
113	1563	6.4	60.6	35.0	35.2	48.0	52.5	15.8	17.3
114	1581	7.0	64.0	29.0	31.2	51.5	57.7	15.6	17.4
115	1590	5.5	72.5	22.0	23.3	52.6	55.8	15.9	16.9
116	1674	44.0	37.0	19.0	34.0	29.0	53.0	8.1	14.7

TABLE III—Continued

FOREIGN COALS

Coal No.	Test No.	(Proximate Analysis of Dry Coal) Ash	Fixed Carbon	Volatile Matter	Volatile Matter In Pure Coal	Results Oil Yield % of Raw Coal	% of Pure Coal	Remainder Coal % of Raw Coal	% of Pure Coal
1	1346	14.8	55.0	31.2	36.2	52.0	60.2	26.0	29.8
2	1349	15.7	53.6	31.0	36.5	43.8	51.7	25.4	29.3
3	1351	23.7	47.0	29.3	38.4	37.0	48.4	19.3	24.3
4	1354	28.9	43.3	27.8	39.0	31.5	44.2	27.3	36.4
301	1594	32.5	25.5	42.0	62.4	35.0	53.0	4.2	6.3
302	1595	16.8	37.8	45.4	54.5	39.0	48.0	4.3	5.3
303	1655	16.5	32.5	51.0	61.0	37.0	44.0	8.6	10.3
304	1628	5.0	63.5	31.5	33.2	49.0	51.0	17.4	18.3
305	1654	4.5	63.5	32.0	33.5	58.0	61.0	11.3	11.9
306	1642	27.0	48.0	25.0	34.3	48.0	66.0	10.0	13.8
307	1622	36.0	34.0	30.0	46.8	27.0	43.0	10.7	17.0
308	1633	14.8	43.6	41.6	48.8	56.0	66.0	1.0	1.2
309	1646	16.7	42.5	40.8	49.0	52.0	63.0	1.3	1.6
310	1854	7.3	61.0	31.7	34.2	50.0	54.0	15.5	16.2
311	1879	11.6	56.0	32.4	36.7	53.5	60.3	15.0	17.5
312	1883	7.6	60.7	31.7	34.3	60.0	65.0	13.4	14.5
403	1878	17.2	41.8	41.0	49.5	54.2	56.0	8.9	10.7
499	1430	15.0	45.0	40.0	47.0	64.3	25.0	0.9	1.1
401	1902	12.2	54.3	33.5	38.2	46.5	37.0	17.0	21.0
402	1853	12.2	57.8	30.0	32.4	46.2	33.2	17.2	18.7
404	1882	9.9	61.6	28.5	31.6	50.1	61.7	14.5	15.9
405	1859	13.0	61.5	25.5	29.4	49.2	37.2	19.8	23.0
406	1884	4.7	78.8	18.5	19.4	47.2	48.0	34.6	35.2
407	1920	11.4	70.6	18.0	20.3	28.7	32.4	25.6	28.9
408	1895	11.0	35.0	34.0	38.2	32.0	67.7	14.1	16.5
411	1896	21.8	49.6	28.6	36.8	41.0	34.0	16.6	21.7
501	1695	13.7	47.6	38.7	45.0	54.0	63.0	2.1	2.4
599	522	11.6	40.0	48.4	54.6	34.0	67.7	11.8	14.8
502	1929	8.4	64.4	27.2	29.6	62.2	68.0	15.7	17.1
601	1691	7.5	51.3	41.2	44.4	58.0	62.8	10.2	11.0
723	1292	18.8	47.5	33.7	41.5	56.4	62.0	4.1	4.5
723a	1758	18.3	47.2	34.5	42.2	56.0	71.5	2.8	3.6
723b	1762	14.5	49.9	35.6	41.6	56.2	72.8	2.7	3.5
723c	1761	14.7	48.5	36.8	41.9	54.4	77.5	3.1	4.4
724	886	14.3	62.2	23.5	27.5	38.0	45.4	13.4	18.0
801	1369	18.3	43.9	37.8	41.3	47.5	63.6	4.3	5.7
802	1391	2.0	32.	66.0	67.3	35.0	35.7	18.0	18.4

TABLE III—Continued

BITUMINOUS COAL FROM RHEINLAND AND WESTFALIA

(Proximate Analysis of Dry Coal) — Results

Coal No.	Test No.	Ash	Fixed Carbon	Volatile Matter	Volatile Matter In Pure Coal	Oil Yield % of Raw Coal	Oil Yield % of Pure Coal	Remainder Coal % of Raw Coal	Remainder Coal % of Pure Coal
201	1553	5.3	58.0	36.7	38.7	45.7	50.8	18.8	21.7
202	1497	4.7	60.3	35.0	36.8	40.0	44.0	21.2	24.0
203	1545	5.6	62.0	32.4	34.4	48.5	52.5	17.0	18.6
204	1546	4.6	62.8	32.6	34.2	42.5	44.5	25.0	26.3
205	1509	5.0	65.2	28.9	31.4	39.0	41.0	25.4	27.0
206	1478	31.6	49.5	18.9	29.4	36.4	55.8	10.3	15.7
210	1539	6.2	83.0	10.8	11.5	43.3	46.7	37.6	43.0
211	1543	7.7	82.6	9.7	10.5	40.0	44.0	40.7	44.5
215	1586	6.2	70.3	23.5	25.0	50.5	54.2	23.0	25.0
216	1565	6.0	73.0	21.0	22.4	51.4	54.7	26.4	28.1
217	1567	7.4	73.1	19.5	21.1	45.0	48.6	32.0	34.6
218	1560	11.2	68.3	20.5	23.0	38.7	44.9	22.2	25.7
207	1570	6.3	65.8	27.9	29.4	52.2	56.0	22.2	23.8
208	1531	3.1	73.7	23.2	24.0	35.6	37.0	23.0	24.0
209	1534	4.0	70.0	26.0	27.0	42.3	44.0	27.0	28.0
212	1591	1.1	82.0	18.9	17.1	37.0	38.0	30.0	31.0
213	1550	9.5	75.5	15.0	16.6	33.7	37.8	26.3	29.5
214	1551	7.5	73.0	19.5	21.1	40.5	45.3	23.3	26.0
210	1615	8.6	60.5	30.9	35.9	48.8	54.0	10.5	11.6

OTHER GERMAN BRANDS OF COAL

(Proximate Analysis of Dry Coal) — Results

Coal No.	Test No.	Ash	Fixed Carbon	Volatile Matter	Volatile Matter In Pure Coal	Oil Yield % of Raw Coal	Oil Yield % of Pure Coal	Remainder Coal % of Raw Coal	Remainder Coal % of Pure Coal
252	915	13.2	66.8	20.0	23.0	36.	41.5	18.	20.8
220a	1682	9.3	67.7	23.0	25.4	40.	45.	27.6	30.0
220b	1677	17.7	58.0	24.3	29.5	42.	51.	22.0	27.0
220e	1745	11.2	64.2	24.6	27.7	41.0	46.2	26.4	29.8
220f	1743	18.1	60.5	21.7	26.4	38.6	47.2	24.2	29.6
224	1777	18.3	66.7	15.0	18.4	41.2	51.2	22.0	28.4
225		18.0	61.3	20.7	25.2	48.5	52.0	19.3	20.7
226	1807	6.5	70.3	23.2	24.3	46.0	49.0	24.3	26.0
227	1809	5.6	72.4	22.0	23.4				
221	1789	24.0	54.5	21.5	28.3	43.0	60.0	13.3	18.5
222	1816	7.7	68.5	23.8	25.8	48.0	57.0	17.1	20.0
232	389	11.0	50.5	38.5	43.3	56.0	63.0	3.2	3.6
233	1084	5.5				35.0	37.0	14.0	14.8
228	1858	8.0	56.5	35.5	38.5	68.0	80.0	0.6	9.7
231	1926	34.5	37.0	28.5	43.5	42.8	66.0	3.3	5.11

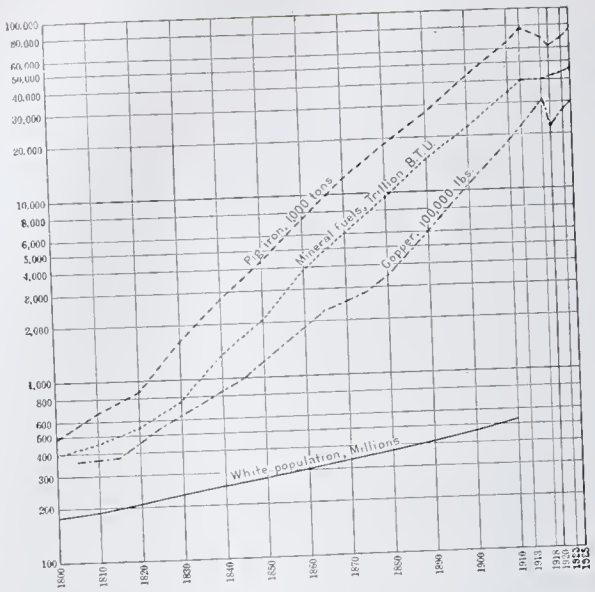
Pig Iron, 1000 tons
Mineral fuels, Trillion B.T.U.
Copper, 100.000 lbs.
White population, Millions

FIG. 7

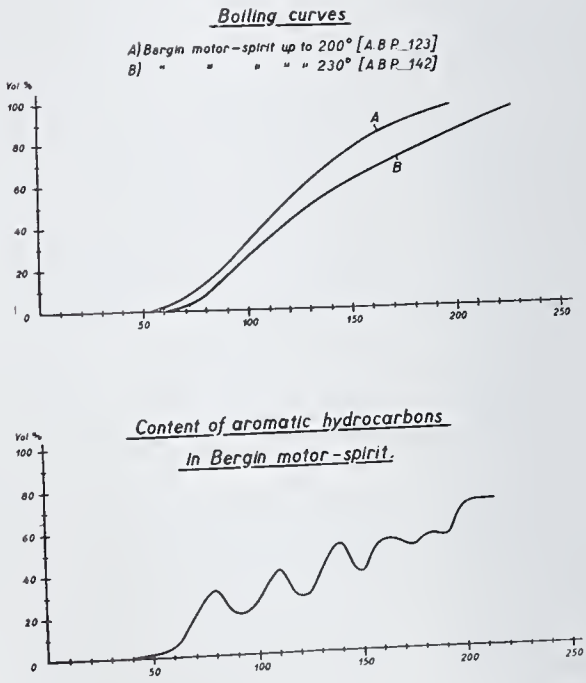
Boiling curves
A) Bergin motor-spirit up to 200° [A B P 123]
B) " " " " " 230° [A B P 142]
Vol %
A
B
Content of aromatic hydrocarbons
In Bergin motor-spirit.
Vol %

FIG. 8

10% and the water contained is not higher than 5%. If the ash content is much higher, obviously the oil output is correspondingly lower.

The products of the liquefaction process are quite different from the tars which are produced by distilling coal at high or low temperatures. Fig 7 is a chart showing the various products derived from an average coal by the hydrogenation method. You will see that one thousand kilos of coal give 150 kilos of marketable gasoline, 200 kilos of a middle-fraction including gasoline and impregnating oil and a residue from which 60 kilos of lubricating oil and 80 kilos of fuel oil can be obtained. Calculated in short tons and gallons, one short ton of bituminous coal delivers about 45 gallons of gasoline, with an end point of about 437° F.

The gasoline fraction contains a very large quantity of aromatic and hydro-aromatic compounds and acts in a motor like a mixture of benzol and gasoline, eliminating knocking. Fig. 8 gives boiling curves of this gasoline. When diluted with normal gasoline, a non-knocking motor fuel is produced.

The recovery of good lubricating oils was a very difficult question in the beginning, but during the past year, in our laboratory as well as in the laboratory of the well-known German tar combine, Gesellschafthur-Teer-Verwertung, under the guidance of Dr. Spilker, good lubricating materials were produced out of the coal oils. The phenolic part of the products contains normal cyclic phenols, cresols, and xylenols and no large molecules, as do low-temperature tars. It may be practical for this country, which imports considerable quantities of creosotic oils, to recover them and to use them for impregnation purposes.

Obviously, all this information on the quality of products of the different coals could not have been gained from only a small and simple laboratory equipment. Even in the early stage of our research work we had to develop methods for carrying through the coal liquefaction in a continuous apparatus. A great many difficulties had to be overcome before such a continuous apparatus ran satisfactorily. The main problem lay in feeding a solid material like coal into the high-pressure apparatus, and in extracting in the same way the inorganic residues and the small percentage of untransformed coal which remained, out of the highly heated high pressure vessels. After long study an arrangement was devised to meet this need. The coal is ground into small pieces not exceeding 2 mm. in diameter and is mixed with the heavy part of the oil from a prior operation to a pasty, thick mass. The material in this form can be easily forced by specially designed pumps into the high pressure vessels, in which

the paste is heated together with the oil already contained in the vessel, to reaction temperature. Hydrogen is pumped in at the same side of the vessel which is equipped with a stirring rod. As you see in Fig. 9 the

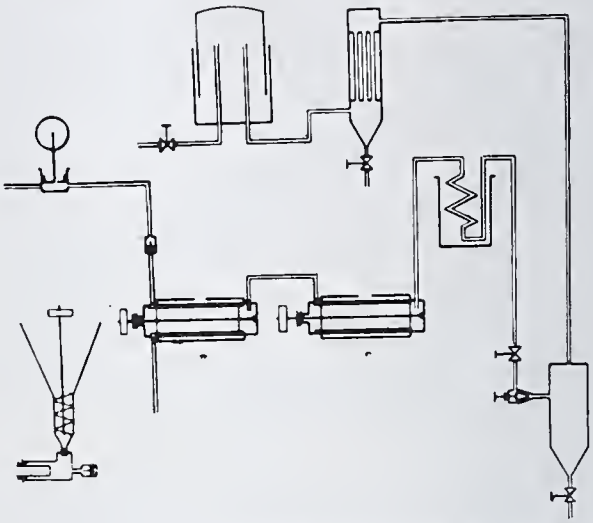

FIG. 9. DIAGRAM SHOWING THE ARRANGEMENT OF CONTINUOUS PLANT

reaction vessels can be combined. The whole of the reaction mass—gas, liquefied coal, untransformed coal and ashes, is drawn out of the vessel and after cooling and reducing the pressure, the gas is separated from the liquid and solid material. It is evident that this expansion can be made after having fractionally condensed the oily products, and that the energy of the compressed gas can be recovered in special engines. Figs. 10 and 11 show the medium-sized experimental plant which is used today for studying different sorts of coal, having a capacity of two short tons in 24 hours. We usually run such plants about six days continuously to determine the products which can be obtained from various sorts of coal or lignite.

We have two such units in our experimental station in Manheim-Rheinau. Another is being erected by the fuel research board of the British Government. Mr. A. Debo and K. Noack were instrumental in working out this method.

In 1916 we began the erection of a bigger apparatus for working under high pressure and with temperatures ranging from 400 to 500° C. For coal liquefaction, a pressure of at least 150 atmospheres, or better, 200 atmospheres or a pressure of 2,200 to 3,000 pounds per square inch, is necessary. Many years were necessary to overcome the engineering diffi-

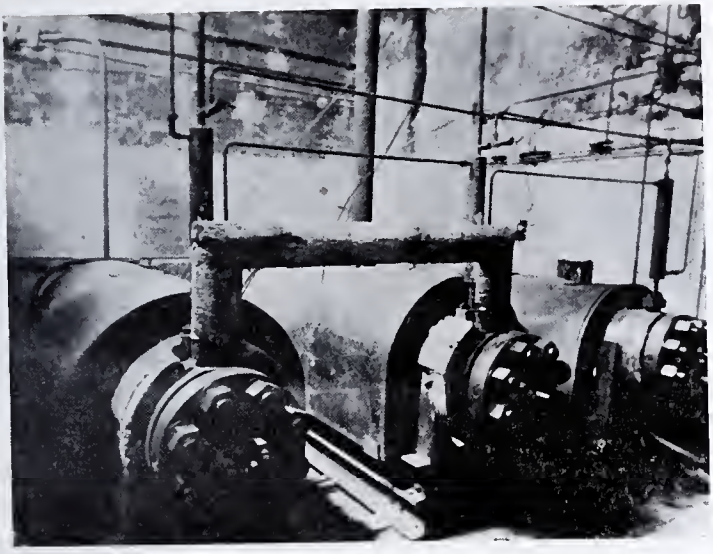

FIG. 10

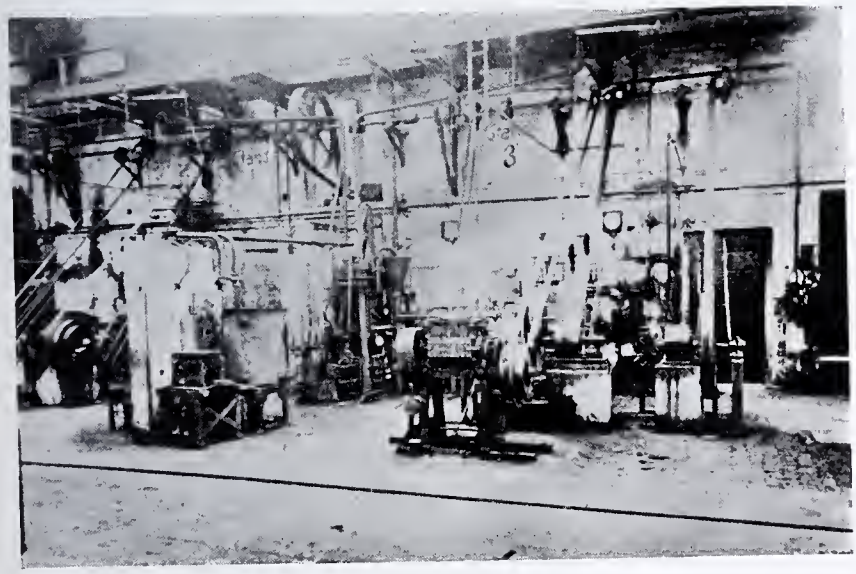

FIG. 11

culties encountered in working under such extreme conditions, as for example, under a reaction temperature of 500° C., at which the strength of steel begins to decrease considerably.

In designing the large apparatus we had the collaboration of Professor Riedler and Professor Loffler of Berlin. The largest part of the technical work of bringing this apparatus to practical operation was done by Mr. Richard Tillman and Mr. Arnold Debo. The method of working this big apparatus is principally the same as that in the experimental station previously illustrated. Besides the difficulty of designing the high pressure apparatus, building pressure-tight enclosures, secure and safe stuffing boxes and valves, and especially the large measurement instalations for controlling the plant, an arrangement for heating had to be devised which controlled temperatures exactly, for the process is very sensitive to changes in temperature. If the temperature is too high, coke is formed; if it is too low, the reaction runs too slowly and the capacity of the apparatus becomes too small. Heating of such apparatus outside of the walls is impossible because the strength of the iron walls at working temperature is not very high, and even requires measures to protect the walls from super-heating. The new heating arrangement especially worked out for this process consists in using as a heat transfer medium a compressed gas chemically indifferent, such as carbon-dioxide or nitrogen which is circulated by a pressure-pump. Through heat exchange between this cool gas and the hot reaction product the latter is cooled, while the gas is heated. After having obtained the final necessary temperature in a special furnace, the heat-exchange gas enters the mantle surrounding the reaction chamber and returns to the circulating pump without being expanded. This heating arrangement allows a very economic control of heat and temperatures because practically all of the heat is recovered. We found that the recovery of heat out of such highly compressed gases can be easily accomplished, and that only small surfaces are needed for the transmission of large quantities of heat.

Figs. 12 and 13 show some of the details of the technical high-pressure plant in Manheim-Rheinau. Fig. 13 is a picture of the research station. Our study through the years has shown that the process can be carried out in this apparatus without danger to the life of the apparatus because the design is made in a way to avoid the attack of hydrogen or sulphur or other reacting material upon the wall of the high-pressure apparatus.

Our own work has given sufficient basis for computing the output of oil and the quantities of power used up.

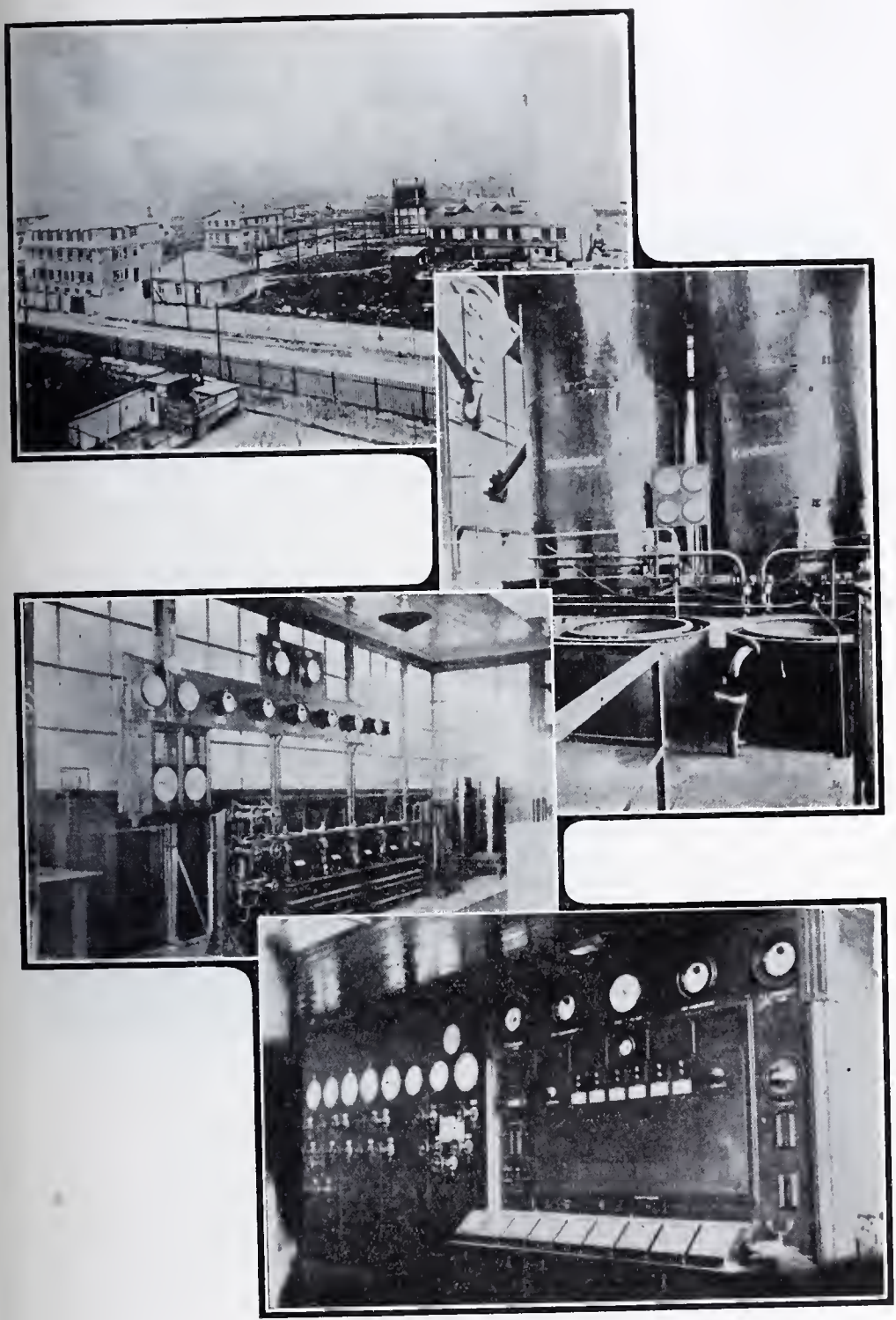

Fig. 12

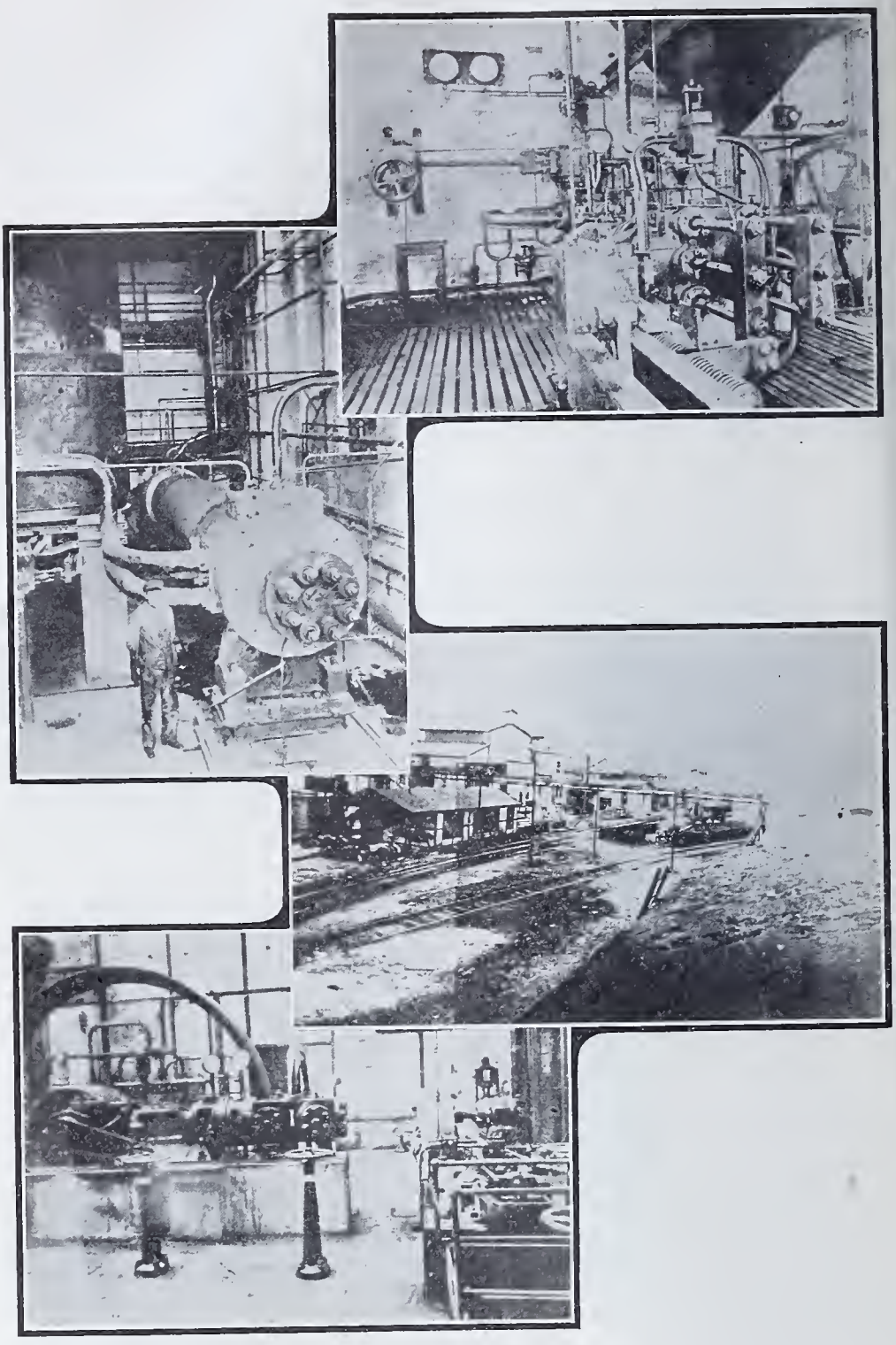

FIG. 13

The basis of calculating the economy of the process is the consumption of raw material and energy, wages and depreciation and cost on the one hand, and the value of the finished product on the other. The raw material is coal or lignite. As coal must be used in ground form it is obviously practical to utilize the fine coal and screenings which are nearly waste products. If a coal contains very large quantities of ash of fusain, washing off by flotation will render it usable for the process.

The second raw material used in the process is hydrogen, and in the production of this material lies the fundamental point of the economy of the process. If coal-liquefaction had to depend on the usual hydrogen manufacturing processes for its supply, then it would be difficult to make oil in competition with the natural product. Other big technical processes, as the synthesis of ammonia and fat hardening, require very pure hydrogen for avoiding poisoning the catalyst, but the coal liquefaction is indifferent to impurities in the gas. Coal will react with hydrogen, if the latter is in a mixture with other gases, as long as a sufficient concentration of hydrogen is present. On this basis a new hydrogen process has been developed for coal liquefaction. It consists in heating the gaseous reaction products in the presence of steam whereby the needed hydrogen is regenerated.

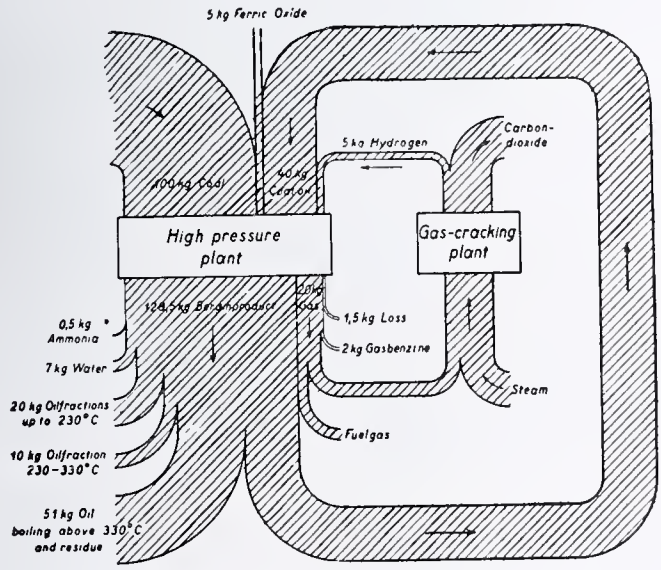

Diagram illustrating continuous operation

FIG. 14

The chemical basis of this hydrogen process is the reaction between methane and water. At a temperature of about 1100° C., one molecule of methane reacts with one molecule of water to give three molecules of hydrogen and one molecule of carbon-monoxide. The latter is transformed by the action of another molecule of steam at a temperature of about 700° in the presence of a catalyst, into carbon-dioxide and hydrogen, so that the total effect of the reaction is a transformation of one molecule into four molecules of hydrogen, theoretically.

Quite similar is the reaction with ethane and steam. By this means it has become possible to make a sufficient quantity of hydrogen out of the reaction-gases to sustain the process. Fig. 14 is a diagram of the combination of coal liquefaction and hydrogen production; note that a certain quantity of the oil produced returns into the apparatus in the form of oil-paste mixed with the coal. The addition of a small quantity of iron oxide has proved advantageous to the process.

Besides the coal used for the reaction, there was obviously a quantity of coal necessary for heating and for making the power necessary to compress the hydrogen. Fig. 15 shows the total balance of material used and recovered in the process. Obviously, it will be posible, in developing the

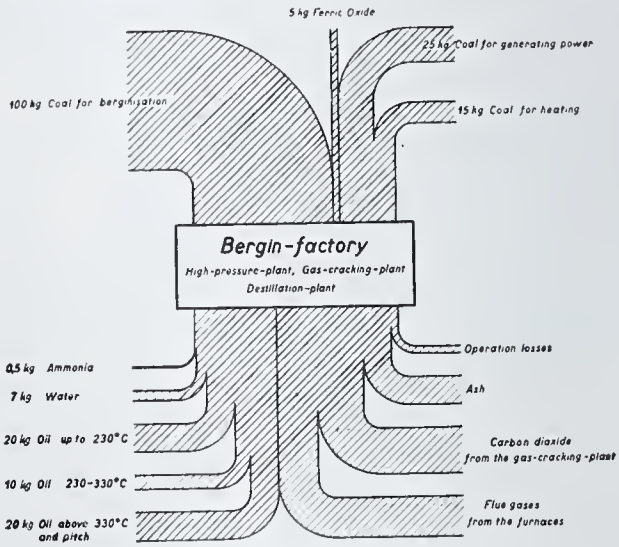

FIG. 15

proces, to economize more heat and power, and to decrease the quantities of coal used in the process now.

In a long period of years and after spending some millions of dollars in a research station, employing on the average 150 men, the coal lique-

faction process was worked out in a technically practicable and economically satisfactory form. After this point was reached in the last year, it became possible to begin the erection of two big factories for coal liquefaction in Germany, one in the lignite territory under the auspices of the Gesellschaft Badische-Anilin-und Sodafabrik, the other in the Ruhr territory by the F. G. Farhen industries fur Teer Verwertung under the management of Dr. Spilker. The total production of both these factories will be nearly one million barrels a year of the different oily products out of coal.

The coal-liquefaction process can be used in many different forms. That which I have explained to you is probably the purest and most concentrated use of it, and makes the process fully independent of any other material or industrial supply than coal itself. It may be used wherever coal or lignite is to be had. From the financial and economic point of view, a plant for the liquefaction of coal must be compared with all technical equipment and machinery necessary for the production of crude oil out of the sand, the pipe lines and the additional equipment for refining the crude oil and producing the various distillates thereof, namely, gasoline, Diesel oil, lubricating oil, etc. This standpoint may seem illogical because it does not include the coal-pit installation, but the situation that big quantities of fine coal and screenings and easily recoverable lignites are available, and can be economically used, justifies it.

There is still another factor in favor of coal liquefaction, that is the stability of production. A coal deposit can be depended upon to yield its product much longer than any oil field.

Ladies and gentlemen, allow me to take a few more minutes to complete this short sketch of coal liquefaction by drawing pour attention to its application to some special fields.

You will recall that so far we have seen how coal, by hydrogenation, can be converted into liquid products, how by this process the world's oldest solid fuel can be converted into what we might call synthetic petroleum, and all the various distillates derived therefrom.

You might quite correctly answer that Providence has given this country such a generous supply of the natural product, namely crude oil, that any process for producing some synthetically, is, at least for the time being, of hardly more than scientific interest.

And yet there are applications of this process which may even right now be of importance to some of the largest industries of the country.

In Fig. 14 you have seen how part of the oil produced by the process is used for mixing the original powdered coal into a paste. Together with the coal it goes through the process once more, that is to say, the oil is once more split up and hydrogenated in the apparatus.

We have found, however, that instead of using part of the oil product in our process for making the coal paste, we can just as well take other oily substances, as for instance, coke-oven tar or low-temperature tar, both of which are available in this country.

The tars are split up and hydrogenated together with the coal and are thereby converted into products of much higher value, practically the same as if we had used our own oil. This fact is particularly interesting as you all know of the difficulties to convert the low-temperature tars and pitches into more valuable and marketable products.

Even more important for this country might be another application of the hydrogenation process. Let us go back to Fig. 4. We have seen there that about 15 to 20% of the coal fed into the apparatus was converted into methane and ethane. Expressed in caloric value, the gas produced by the coal-liquefaction process is equivalent to the gas obtained from coal by the ordinary coking process for the production of lighting gas.

In other words, a coal liquefaction plant can well be looked upon as a highly improved ordinary gas plant, for the simple reason that the gas produced has the same caloric value, while our by-product, namely, oil, is worth considerably more than the coke of the ordinary gas plant.

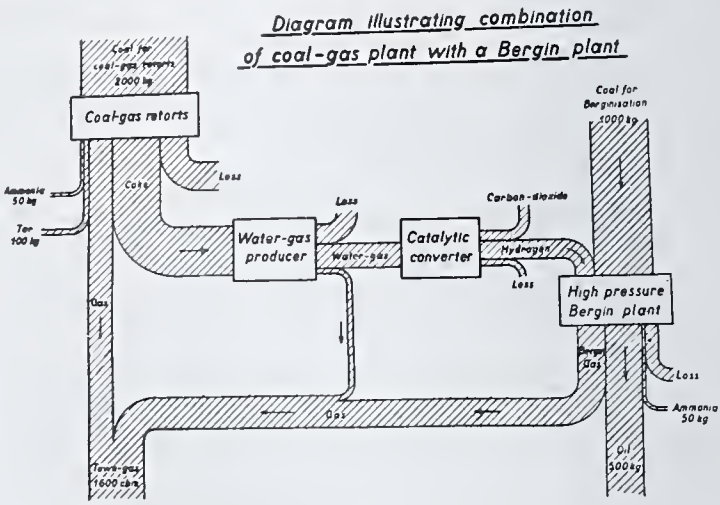

FIG. 16

In addition to the more valuable by-products we have another advantage of great economical importance inasmuch as we can use an inferior and, therefore, cheaper coal than the one required by the ordinary gas plant. In this case, of course, part of the coke produced by coke oven or low-temperature distillation plant has to be set aside for supplying the hydrogen necessary for liquefaction.

In Fig. 16 I have tried to show you how an existing gas plant may be combined with a coal liquefaction plant. From the coke produced in the gas plant, the hydrogen necessary for the liquefaction process can easily be obtained, according to well known methods. Instead of obtaining gas and coke as final products, such a combination plant yields instead of coke the more valuable oil, and a gas of much higher caloric concentration. This gas can be mixed with water gas, whereby the required caloric concentration of ordinary gas can easily be obtained. If kept in the compressed state, the transport of gas out of coal liquefaction on account of its smaller volume, is obviously cheaper than that of ordinary gas.

The all important question the world over is the most economical utilization and conservation of the specific raw materials that Providence gave to each country. Europe is not in the fortunate position of the United States with its enormous natural resources, with an oil supply which only a short time ago seemed to be inexhaustible.

And yet, the time may come sooner than anybody here can foretell when the decreasing natural oil supply of this country will not meet the ever increasing demand any longer, when the United States will be confronted by the same problem which we in Europe are facing today. (See Report of Conservation Bureau.)

Let me thank you, ladies and gentlemen, for your kind attention and let me assure you that I should be happy and proud if our endeavors to solve one of the greatest problems which Europe is facing today, namely, the creation of an adequate oil supply, should also be of some benefit to this country.

DISCUSSION

W. TRINKS.* I notice you add iron oxide. Is that a catalyst, or what is it?

FRIEDERICH BERGIUS. You are asking more than chemistry can give at this moment. We have found that the presence of sulphur in coal, coal products, or oils may cause polymerization and that means coke formation. Such polymerization product is always formed at a higher temperature. We have found that by adding a little iron oxide it practically avoids such danger.

Our opinion is that it has the effect of taking away some special form of sulphur which endangers the reaction and which makes the coke formation easier—that has been our experience.

JACQUES MORRELL.† You have shown the composition of the distillates from the reaction. Can you tell us the composition of this distillate which boils between 150°C. and 230°C.? Is it a pure distillate such as can be used right away as gasoline, or is it a product containing a large quantity of oxidized bodies which would have to be purified.

FRIEDRICH BERGIUS. Up to 230°C., before being refined, it contains some xylenols that are taken out, but the figures which I have given you are for the neutral gasoline remaining after taking out all the oxygen containing phenolic products.

JACQUES MORRELL. What is the quantity of oxygen containing material in the crude distillate from 150°C. to 230°C.?

FRIEDRICH BERGIUS. The figures I give here are free from oxygen containing materials, and I have shown you the boiling point of the product—I can't tell at this moment how much. It boils at 150°C., but the product made this way is made according to the usual methods of gasoline motor fuels.

A MEMBER. Would it be possible to use a bone coal of about 30-35% volatile matter and about 25-30% ash and about 1% sulphur content—or would the high ash ruin the process?

FRIEDRICH BERGIUS. Any such question is difficult to answer, without knowing the coal exactly. From a normal analysis it is not possible to say. Our experience is that in the case of coals containing 24% of ash, it would be more practical, before treating it by hydrogenation, to bring down the ash; because it is cheaper than to bring so much ash through a high pressure plant. The whole question can only be answered where a person knows the coal exactly.

A MEMBER. You outline what products are given off in the process. I wonder if you can tell us what the cost of this material will be when these products are formed? Of course I realize that labor costs in Germany are different, but I am trying to estimate the products per ton

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with what we would get out of it, if we went through the process in this country. In other words, give the total cost of the materials up to the point you had on the chart—gasoline, oil and other products?

FRIEDRICH BERGIUS. I was in this country fourteen years ago for six weeks, and have now been here for four weeks, and it is very difficult to transfer costs from Germany to America in the same minute; but so far as I have observed things coal varies in different places, and I would think about 40 to 45 marks per ton of coal would be the average cost here, in big plants, for one ton of coal in finished products—not including the coal.

A MEMBER. Do you consider the motor fuel fraction as being formed from the cracking of the heavier hydrogenated products, or are they formed by direct hydrogenation?

FRIEDRICH BERGIUS. That is also a difficult question to answer. I did endeavor to make clear that this reaction is a combined one, hydrogenation first, and then splitting up.

I can find out the moment in which perhaps two to three per cent of the weight of coal and hydrogen are added, but while the product is in the crude state partly melted it is in this state, but only becomes liquid at a little higher temperature. During the split-up it gives off hydrogen. If such split-up could be done like the cracking of oil there would be no liquid products—only a small quantity would form, and about sixty per cent of coke. But during the second part of the reaction the material is split up and you have an action of melting which cannot be compared chemically with normal cracking processes, because all this hydrogen must be present.

A MEMBER. Would it be possible in the hydrogenation of your partially cracked material to proceed in the same manner as with the hydrogenation of the original coal?

FRIEDRICH BERGIUS. Your question is "whether the partially cracked pitchy material resulting from the cracking of the original heavier hydrogenated product—can that be hydrogenated as well." It seems to me when you come to the expression "cracking" the chemical meaning of it, by pure cracking, you get coke.

A MEMBER. I realize that is a difficult question, but I wanted to get an expression from you as to whether you had any concrete idea as to the result of the cracking?

FRIEDRICH BERGIUS. We have hydrogenation.

A MEMBER. How is the ash residue removed?

FRIEDRICH BERGIUS. That is one of the most difficult questions. Out of the reaction vessels there comes a solid residue going out this tube to a vessel in which it is cooled down. After cooling down such material is more easily taken out under high pressure. That is why we had to design special valves.

A MEMBER. I am interested to know what is involved in the recovery, the separation and refining of the motor fuel fraction and oil, and

how is it accomplished in your country? How separated and how refined—does it have to be washed with sulphuric acid?

ANSWER. Motor fuel consists of about 50-55% of the material. It takes only a small washing, washing with sulphuric acid is the usual way—all the small quantities of sulphur are taken out.

A MEMBER. The subject of making the coal fine, prior to the high pressure work, and that coal being made into paste—did you indicate what liquid was used in making the paste?

FRIEDRICH BERGIUS. I believe I told you that the liquid is first made out of the heavy parts of the oil, and I showed you a picture—you will perhaps remember it—in which the oil was mixed with the coal.

FRANK M. GENTRY.* We have been most fortunate in listening to a paper by Dr. Bergius, wherein he has told us of his most remarkable and now world famous researches on the hydrogenation of coal. When I think of the work being done today on the fixation of nitrogen, the synthesis of methanol and the liquifaction of coal, I am forced to conclude that science and engineering are entering upon a new era of very high pressures and very high temperatures. Dr. Bergius has made inestimable contributions to his pressure chemistry and to the technique of high pressure procedure. Still higher pressures and still higher temperatures will undoubtedly be attained, but it seems to me that we have just about reached the limit in these respects with the materials and methods we now have available. Future progress rests with the metallurgists to give us alloys which will withstand very high pressure at temperatures well above 1000° F. The corrosive action of the reagents under extreme conditions of pressure and temperature is another difficulty that complicates the situation. An example of this occurs in hydrogenation where the margin of safety is reduced through diminution of the tensile strength of iron and steel by the removal of its carbon content as methane.

A great deal is being done to find catalysts which will effect the liquefaction of carbonaceous solids without recourse to such extreme physico-chemical conditions. Bergius uses a certain proportion of ferric oxide as an addition agent to hold the sulphur in his coal paste during hydrogenation. It seems to me that such a well known catalyst in other cases could not be without its effect upon the reaction rate here. In fact this view is substantiated by the recent experiments of Bowen and Nash at the University of Birmingham who observed that both iron and nickel oxide had a marked catalytic influence when coal was hydrogenated in the dry state. In passing it might be mentioned that Shatwell and Graham at the same university succeeded in hydrogenating in the presence of phenol a coal containing 91.54% carbon, 4.32% hydrogen, 1.85% oxygen, 1.45% nitrogen and 0.84% sulphur. The

*Assistant to the Consulting Engineer, The New York Edison Co. (Submitted in writing after close of meeting.)

liquifaction was about 55% efficient after nine hours treatment under maximum conditions of 430°C. and 37 atmospheres.

Although not generally suggested, hydrogenation can be associated industrially with low temperature carbonization in cases where the semi-coke is desirable for power or other purposes. It will be recalled that primary tar contains a high percentage of tar acids, largely cresol and other phenolic derivatives. These tar acids might be hydrogenated at a conversion efficiency of 60% to 70% thus greatly increasing the yield of light oil suitable for motor spirit.

It is my understanding that Bergius' initial work consisted of heating cellulosic materials under high pressures, obtaining first a black carbonaceous residuum. From these experiments he was able to calculate the age of coal. This should be of great interest to geologists and chemists for it points to the value of synthetic experimentation in the study of the origin and constitution of coal.

Not many years ago when exhaustion of the world's nitrate deposits loomed as a ghastly contingency, our men of science devoted themselves tirelessly to the production of synthetic nitrogeneous compounds, that we might have fertilizer and explosives independent of the saltpeter deposits. Today we are free of that bondage. If I understood Dr. Bergius correctly, Germany will shortly be producing a million barrels of synthetic petroleum a year by berginization of coal. So that again, with the ghost of oil depletion stalking about, science has laid the foundation for a new synthetic industry. Civilization must have its oil and science must provide it.

THE INDUSTRIAL TRANSFORMATION OF BITUMINOUS COAL INTO ORGANIC TECHNICAL PRODUCTS

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1. Bituminous Coal as a Raw Material for the Organic Chemical Industry

The utilization of bituminous coals may be viewed exclusively from the point of view of their use as fuels; that is to say, as a source of calorific energy, utilized directly in this form, or as being transformable into mechanical, electrical, or light energy. It is certain that this mode of utilization is and will remain of primary importance, for the needs of humanity in heat, power and light keep step with the progress of civilization. But this kind of substance taken from the earth may likewise be considered as a source of raw materials for chemical manufacture; that is to say, as the point of departure of a series of chemical reactions having as their goal the transformation of these complex, colloidal, organic substances into isolated and definite chemical compounds whose consumption increases every day in variety and in quantity to such a point that vegetable and animal matter from which the chemical industry draws them seem to-day to be of an insufficient quantity or of too high a price to satisfy ever-growing needs, which cannot be satisfied completely as long as it is not possible to find raw materials sufficiently abundant. Now bituminous coal, considered as one of these raw materials, has the invaluable advantage of being found in almost unlimited quantities in the earth as a reserve that has accumulated during many thousand years of former vegetation.

2. By-Products of the Distillation of Coal

In fact, the use of bituminous coal—at least for a part—as a raw material for chemical manufacturing, dates back almost to the origin of the manufacture of coke and gas, in which the by-

products of the distillation of coal were utilized. But this utilization was always indirect and rudimentary. It was only in attempting to profit from one of the by-products of distillation, tar, that one thought of deriving from it organic products whose exploitation has, moreover, given rise to one of the most important chemical industries, that of dye stuffs. But these tars represented, and still represent, only a by-product of very small importance, at least in quantity, since they constitute, with the normal methods of manufacture of coke and gas, scarcely 5% of the amount of coal distilled, and in the tar itself the elements usable in the chemical industry (benzol, toluol, phenol, naphthalene, anthracene, etc.) are present only in very small proportions. Progressively, nevertheless, and considering the importance of the applications of these products derived from coal tar, their extraction has become more and more nearly perfect. It was noticed that in the gases of distillation themselves, certain volatile products (such as benzol and toluol) were carried over in the state of vapor, in considerable quantities, and the most ingenious processes (the use of liquid solvents and solid adsorbents) were devised to separate them from gases and recover them with the view of special utilizations.

This recovery of the chemical products of the distillation of coal developed, moreover, but slowly, for it met with the objection that it would not be profitable; and in 1913 the quantity of metallurgical coke produced in the United States in by-product ovens represented but 27.5% of the total quantity of coke produced.[1] Nothing but the extraordinary needs in benzol and especially in toluol, and the very high prices that were the result of this, brought on by the intensive manufacture of explosives in the course of the European War of 1914-1918, were sufficient to induce the manufacturers of the United States to modify their plants or to establish new ones in view of this recovery of by-products. This is why at the present time the percentage indicated above has been inverted, and the coke produced in 1925 in ovens in which the recovery of by-products is carried out represented almost 79% of the total quantity produced.[1] The increase of this proportion indicates clearly the increasing interest that the industrial world attaches to the

value of these products and the greater and greater encroachment of the requirements of the chemical industry on the treatment of bituminous coals.

3. Low-Temperature Distillation

From the point of view of the recovery of by-products considerable effort has been made, principally in the course of the last few years, to systematize the modifications undergone by the coal in the course of the distillation, to improve upon the crudeness of the old methods, and to prevent the decomposition of the by-products that result. It is thus that the so-called "low-temperature" carbonization, that is to say, in which no part of the charry mass was subjected to a temperature higher than 600° C., yielded tar in more abundant quantities than the previous processes; and this tar differed from that obtained with temperatures in the neighborhood of 1000° C. in its much greater fluidity, in its content in free carbon, in the almost total absence of aromatic hydrocarbons such as benzol and toluol, and in its important proportions of higher phenols of which certain ones were very viscous and even resinous. Up to the present these tars, whose composition varies according to the nature of the coal, and is still insufficiently known, have been put on the chemical market only in relatively small quantities, and have not yet found the utilization that will not be lacking when the chemical industry knows that it can have sufficient quantities at its disposal. This example shows, however, to what degree variations of an elementary character in the thermal decomposition of bituminous coals modify the nature and the proportions of the by-products that can be derived.

The numerous studies undertaken to better, in this respect, the processes of distillation of bituminous coals have, as a matter of fact, been carried on from their beginning and in their principle itself, with the almost exclusive purpose of improving the quality of the solid residue of distillation and of certain portions of the distillate in regard to their quantity or their properties as fuels, and with the idea of the more advantageous use that might be made of them either in the home or in metallurgical furnaces, or in internal combustion engines. Their physical and chemical properties

[1] Chemical and Metallurgical Engineering. Vol. 33, (1926) page 17.

are scarcely appreciated from this latter point of view, which is wholly different from that which we have adopted, and which concerns solely their use in the organic chemical industry.

4. Fractionation of Coal by Solvents

Just as the action of heat and the decomposition that results from it permit deriving from bituminous coals only relatively very small quantities of organic compounds interesting to the industrial chemist, the methods tested up to this time for the separation of the elements of the complex conglomerate that these coals present —if they have permitted throwing some light on the constitution of these products and on the results that can be expected in the manufacture of coke—have yielded up to now, from the special point of view that occupies us, only results still less usable industrially than the distillation by the action of heat.

The most varied solvents (liquid sulfurous acid, benzene, phenol, pyridine, etc.), used even under pressure at high temperatures, have permitted the separation of only a small percentage of oils, and of resinous or bituminous substances badly defined, for which, up to the present, no possible technical uses have been found.

5. Controlled Oxidation

The attack of crude coal by the chemical agents that are usually employed did not lead to perceptibly better results. By a careful oxidation attempts have been made to extract from coals other things than carbonic acid and water. Pure oxygen and ozone have been used in the presence of water or of alkaline solutions, with varying temperatures and pressures; likewise the action of hypochlorites, of persulfates, of chlorates, of nitric and sulfuric acids, has been tested without obtaining anything but solutions of organic acids offering scarcely any possibilities of practical utilization, to say nothing of the high cost of production that would result from treatments so costly if one wanted to put them to use in industry.

6. Hydrogenation of Coals

The method of treatment by the action of hydrogen under pressure, due to Doctor Bergius and known by the name of "Berginization" seems, on the other hand, to have led to remarkable

results that permit the transformation of a very considerable fraction of bituminous coal into gaseous and liquid hydrocarbons, the latter being analogous to the oils of petroleum or to their derivatives. This process, very interesting from the point of view of the fuel industry, in that it permits transforming solid coal into liquid fuels of a much higher value, solves, however, only partially and incompletely the problem of the direct production—starting with coal and water as the only raw materials—of organic compounds technically usable by the chemical industry, and in particular, of oxygenated organic derivatives; for the hydrocarbons obtained by Berginization are themselves very difficult to transform into their oxygenated organic derivatives, and the studies that have been carried on for a very long time, especially in the United States, for the production of alcohols or of aldehydes starting from hydrocarbons of petroleum have but quite recently led to results suitable for an industrial exploitation, of which, however, the success seems still very uncertain.

7. Indirect Method by Synthesis from the Gaseous Derivatives of Coal

It follows from what precedes that up to the present time the direct treatment of bituminous coals by physical or chemical methods, with the view of the production of organic compounds and of a technical use for the chemical industry, has not led to a complete industrial solution of the problem.

On the other hand, there exists to-day an indirect method to which we have particularly devoted our studies, which starting with any kind of coal (and, in general, with any combustible substance) permits after complete gasification the production of a considerable series of organic products usable by the chemical industry.

This method is based on the direct combination by catalytic synthesis under pressure of carbon monoxide and hydrogen with the formation, in theoretical quantities, not only of methyl alcohol, but of other homologous alcohols, as well as of acids (esters) and of ketones which lend themselves to the most diverse and important industrial uses.

In fact, if one passes in a closed circuit over appropriate catalysts maintained at a sufficiently high temperature gaseous mixtures containing carbon monoxide and hydrogen in suitable pro-

portions, compressed to relatively high pressures, it is ascertained that by cooling to atmospheric temperature the gaseous circuit at the outlet of the catalysis apparatus, there are separated in a liquid state methyl alcohol and, according to the nature of the catalytic agent, other alcohols and oxygenated organic products derived from alcohols. The yield (to say nothing about mechanical losses) does not differ perceptibly from the theoretical yield corresponding to the equations:

$$(1)\quad n\,CO + 2nH_2 = C_nH_{2n}{-}OH + (n-1)\,H_2O$$

$$(2)\quad p\,CO + pH_2O = pH_2 + p\,CO_2$$

By varying the nature of the catalyst and its temperature one can obtain either pure methyl alcohol ($n = 1, p = o$), or a mixture of homologous alcohols of the same family (methyl, ethyl, propyl, isobutyl, etc.) with a variable and generally very small proportion of free or combined acids, of ketones and of tarry residues. With the use of special catalysts the proportion of acids, and, in particular, that of isobutyric acid, can be very notably increased.

This process, which is at the present time completely practicable for industrial production, is already in operation in Germany on a large scale (since methyl alcohol thus obtained has already been imported in considerable quantities into the United States) and will function soon in France, also in other countries of Europe, as well as in the United States.

We do not think that it falls within the scope of this conference for us to elaborate particularly on the details of the operation of the process. The few photographs that we include in our paper were taken of a semi-industrial plant of a normal capacity of production of 150 to 200 kilogs. per 24 hours at Vitry-sur-Seine in the Etablissements Poulenc Frères in France, and will illustrate the simplicity of the installation.

There is shown:

In Fig. 1: A watergas producer with its gasholder.

In Fig 2: The apparatus for the purification of the gases obtained.

In Fig. 3: The compressor (300 atmospheres) and the circulation pump for the gaseous mixture.

In Fig. 4: The distribution apparatus for the gas with the catalytic and pressure control apparatus.

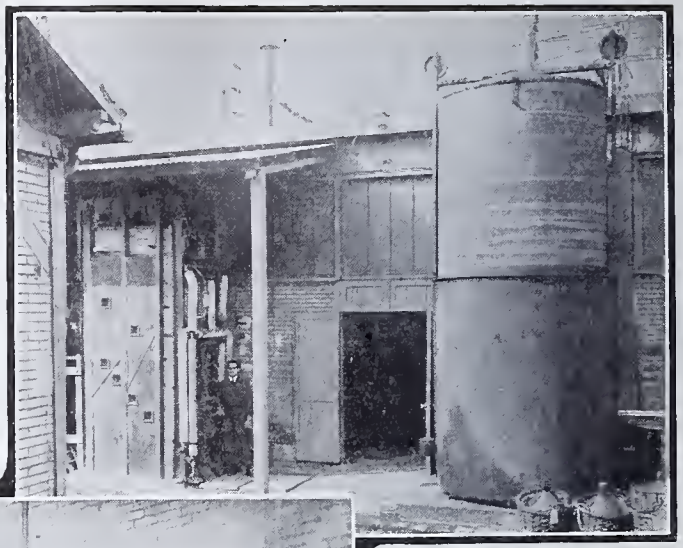

FIG. 1

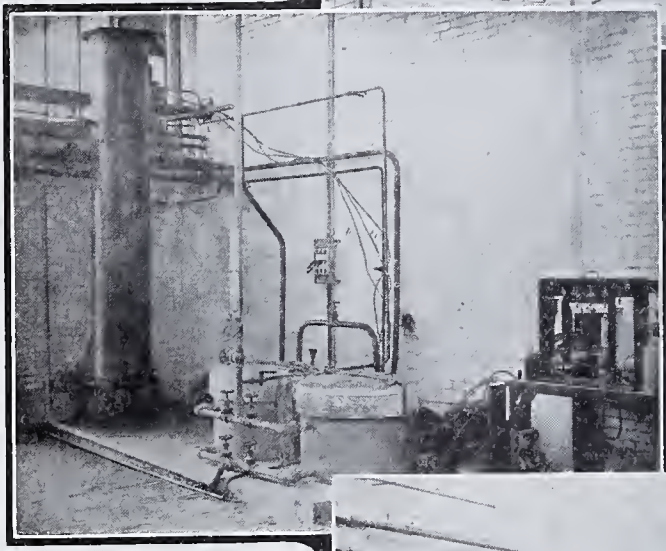

FIG. 2

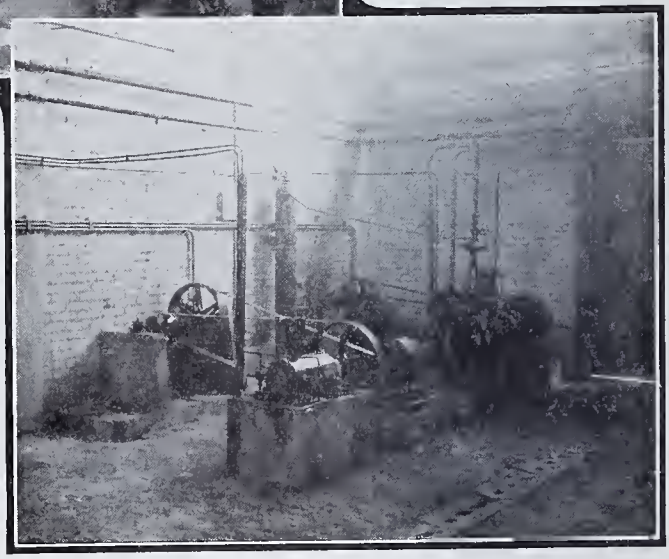

FIG. 3

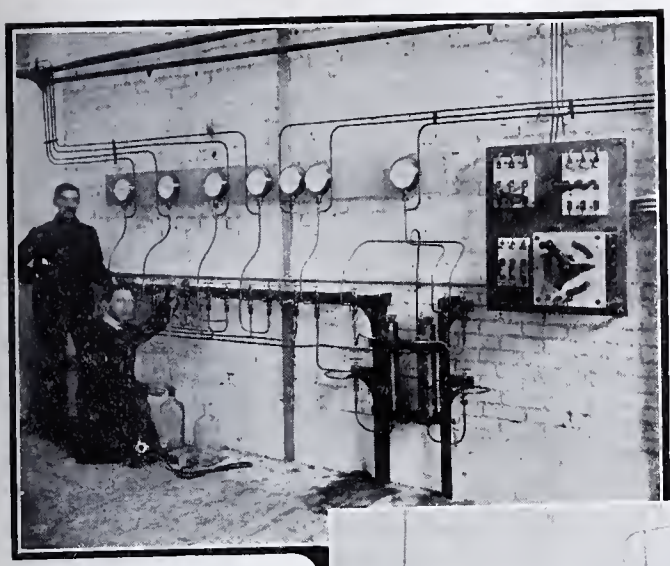

FIG. 4

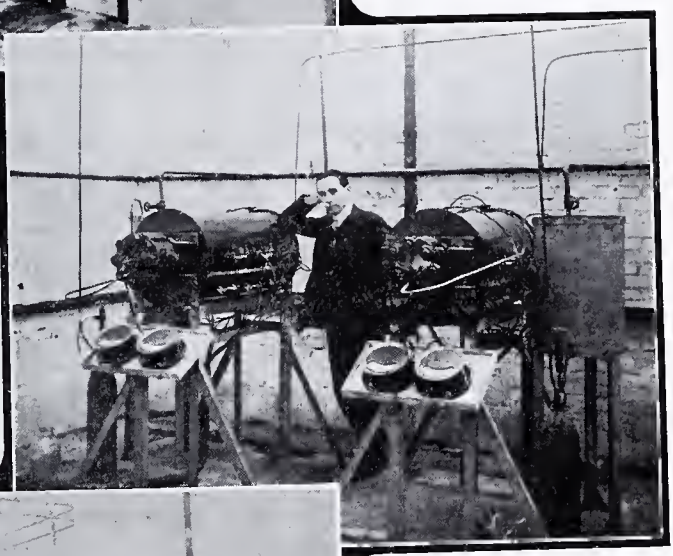

FIG. 5

FIG. 6

In Fig. 5: The ensemble of the two catalysis tubes with their heating jacket, their coolers and condensers.

In Fig. 6: The recovery of the methyl alcohol obtained from one of the receivers in which it is collected.

We believe that we are to emphasize here only the characteristics of this manufacture that concerns particularly the use of bituminous coal—the very subject of this conference—as the only raw material, and the industrial profit that can be derived.

8. Analogies of the Synthesis of Alcohols and of the Synthesis of Ammonia

It is interesting to bring out that the synthetic manufacture of alcohols shows the greatest analogy with the synthetic production of ammonia by direct combination of nitrogen and of hydrogen, for it is a question alone, in both cases, of the direct combination of two permanent gases obtained by the combined action of pressure and of temperature, in the presence of appropriate catalytic agents; but that the production of alcohols differentiates itself from that of ammonia by certain characteristics of such a nature as to render its industrial realization considerably easier for the following reasons:

1. For a specific production of the same magnitude, all other circumstances remaining the same, the working temperature at which the gases are passed over the catalytic agent, a temperature that can scarcely descend below 550° C. in industrial ammonia synthesis, can be lowered to 400° or 450° C. for the synthesis of higher alcohols and to 350° or 400° when only the exclusive production of methyl alcohol is sought after. For this latter one may even, with certain catalysts, descend to 200° C., but with a moderate output for the apparatus. This lowering of the temperature of reaction is a very important advantage for the construction and conservation of the apparatus.

2. As far as the reactional gaseous mixture is concerned, its composition, which must be maintained in the very narrow limits of proportion and purity of the components to affect a good functioning of the ammonia synthesis, may vary, on the contrary,

within very wide limits when it is a question of the synthesis of alcohols.

It may even be affirmed that almost all the gaseous mixtures in which the total volume of the carbon monoxide and of hydrogen constitutes more than 30% of the mixture and in which the volume of the carbon monoxide is at least equal to half of the volume of the hydrogen, are practically and directly usable for this manufacture on the condition that the other gases be not different from those which are met normally in industrial fuel gases (water vapor, carbonic acid, nitrogen, hydrocarbons); on the other hand, the purification, as far as the sulfurized compounds are concerned, need not be carried further than in the coal gas supplied as a fuel for domestic consumption. Of course, the gases that we shall designate as "inert" (that is to say, other than carbon monoxide and hydrogen, which combine, and which we shall call "active" or "reactional") cannot be permitted to accumulate indefinitely in the gaseous circuit as the two reactional gases are eliminated in the state of the product of their combination. These inert gases must, therefore, be eliminated, either in a continuous manner or in a discontinuous manner, by condensation, solution, liquefaction, or by purging, which involves certain important consequences which we shall emphasize further on.

3. There are for alcoholic synthesis a very large number of catalytic agents (of which the best are those, it seems to us, that are composed of the mixtures of oxide of zinc and of the oxide of chromium, in suitable proportions) giving a very satisfactory practical yield, of much easier preparation, of much greater insensitiveness to the action of the impurities or "poisons", whose activity is persistent and regeneration easier than that of the catalytic agents (iron in particular) used in the ammonia synthesis.

4. The influence of the pressure on the proportion of gases combined at each passage over the catalytic agent is as great, if not greater, in the alcoholic synthesis than in the ammonia synthesis. Of course the pressure that enters into account from this point of view is not the total pressure of the gaseous mixture, but merely the partial pressure of the active elements (carbon monoxide and hydrogen). As this partial pressure with regard to the total pressure is so much the lower, the greater the proportion of inert elements (methane, nitrogen) permitted by the composition of the

gaseous mixture in circulation, it is seen that the presence of the latter has as an inevitable result the reduction proportionally of the output of the apparatus or a corresponding elevation of the total pressure.

9. Special Precautions in the Synthesis of Alcohols

On the contrary, certain special precautions are necessary for good operation in the synthesis of alcohols. Thus, iron has on the gaseous mixtures employed a selective catalytic action tending towards the formation of methane according to the equation:

$$CO + 3\ H_2 = CH_4 + H_2O$$

and lending itself, on the other hand, to the harmful formation of iron pentacarbonyl, $Fe(CO)_5$; as much as possible, all direct contact between the gaseous mixture at a high temperature and the iron of the jackets and piping must be avoided. This can be easily done by lining the interior with copper, aluminum, chromium or any glaze not attacked by hydrogen and carbon monoxide. Nickel possesses analogous properties that are still more pronounced, and one cannot circulate the gaseous mixture, as is sometimes done in the case of the ammonia synthesis, in direct contact with heating coils made of alloys with iron or nickel for a base.

There result from this condition certain difficulties for the interior heating of the catalyst tubes when one cannot resort to heating these from the outside, a method which itself presents serious disadvantages for the resistance of these tubes to the high pressures that they must bear.

10. Influence of the Proportion of Inert Gases

Another peculiarity, characteristic of alcoholic synthesis that relates particularly to the utilization of bituminous coals as a raw material, concerns the presence in the gaseous mixture of what we have called "inert" gases, that is to say, other gases than carbon monoxide and hydrogen, and these are usually carbonic acid, methane and nitrogen.

As far as carbonic acid is concerned it must be remarked that it is not, properly speaking, an "inert" gas, since it is capable of combining with hydrogen to produce methyl alcohol by the reaction:

$$CO_2 + 3H_2 = CH_3OH + H_2O$$

In truth, it is not known exactly whether this reaction follows immediately or by an intermediate stage with a preliminary reduction of the carbonic acid to the state of carbon monoxide and a subsequent combination of this latter with hydrogen. One would have successively:

$$CO_2 + H_2 = CO + H_2O$$
$$CO + 2H_2 = CH_3OH$$

Certain experimental results bring one to believe that it is, in reality, the process in two stages as indicated.

However that may be on this particular point, it is verified in practice that in certain cases, and particularly when the reaction is conducted in such a way as to carry to its maximum the production of higher alcohols, and, above all, when the proportion of the hydrogen in the gaseous mixture is reduced, the concentration of the carbonic acid in the gaseous circuit tends to rise to 20 or 25%, when the total working pressure oscillates in the neighborhood of 250 atmospheres. This carbonic acid can be eliminated in several ways: either by having the gaseous mixture bubble into caustic soda, or, more easily, by compressing into water; or, finally, by liquifying it with a sufficiently low temperature applied at a point in the gaseous circuit beyond where the condensation of the alcohols take place.

Moreover, the reaction of equilibrium:

$$CO_2 + H_2 = CO + H_2O$$

intervenes to limit the amount of the carbonic acid while there is a sufficient excess of hydrogen in the gaseous mixture.

For the elimination of the methane the solution is less simple, because the means of absorption or of solution are practically absent. The process of liquefaction alone would permit, with the use of sufficiently low temperatures, the elimination of the methane that, moreover, would carry along with it a considerable quantity of carbon monoxide, of nitrogen and even hydrogen. But without being impracticable, the application of such low temperatures to containers or piping that have to resist pressures prevailing normally in the gaseous circuit (from 200 to 850 atmospheres) does not occur without bringing up serious difficulties and complicating the installation considerably. The method of purging, continuous

or periodic, although less satisfactory theoretically, will, perhaps often, be the most practical solution for the elimination of this gas.

Finally, for the third inert gas, namely, nitrogen, the process of liquefaction itself would not be satisfactory, the nitrogen being more volatile and consequently condensing only after the carbon monoxide, an "active" product of the gaseous mixture; the liquefaction of the nitrogen would entail, then, the elimination of still greater quantities of carbon monoxide. As far as the nitrogen is concerned, one must, then, be resigned to purging methods, continuous or periodic, that can serve at the same time for the elimination of the methane.

11. Decrease in Yield Caused by the Presence of "Inert" Gases

The purgings of the gaseous mixture in circulation (after condensation, naturally, of the condensable fractions such as the alcohols) involve necessarily the elimination simultaneously with the inert gases (nitrogen and methane) of the reactional gases (carbon monoxide and hydrogen), constituting a part of the same gaseous mixture, which can be, under these conditions, considered if not as totally lost for the synthetic reaction, at least as having undergone a veritable deterioration or diminution in value, from the fact that it will be necessary, if one wishes to use them again, to separate them from the inert gases with which the active gases are found mixed, which fact will require generally a total or partial decomposition and a supplementary treatment, always more or less expensive. Consequently, it is of interest to determine the proportion of active gases that will be found thus carried over into the purgings as a function of the content in inert gases of the initial gaseous mixture serving as raw material and following the proportion in inert gases at which one will stop with the purgings, that is to say of the used gas that it will be judged necessary to permit to escape from the circuit.

If we call (ti) the proportion of inert gases contained in the gaseous mixture upon its introduction into the synthesis circuit, and (to) the proportion of these same gases in the gaseous mixture in circulation at the point when the purging is stopped, a simple calculation shows with a constant normal operation, the fraction (pr) of reactional gases carried along by the purging (and not

utilized for the reaction), relative to the quantity of these same gases introduced into the catalysis circuit, is given by the formula:

$$pr = \frac{ti\ (1—to)}{to\ (1—ti)}$$

which leads to the following values of "pr" for variable values of "ti" and "to".

TABLE I

Values of (pr) for

	to=0.20	to=0.30	to=0.40	to=0.50	to=0.60
ti=0.025	0.102	0.0597	0.0384	0.0256	0.017
=0.05	0.210	0.123	0.0789	0.0526	0.033
=0.075	0.324	0.189	0.122	0.0811	0.0541
=0.10	0.444	0.259	0.166	0.111	0.074
=0.125	0.572	0.334	0.2145	0.143	0.095
=0.15	0.706	0.412	0.2647	0.1765	0.118
=0.20	1.00	0.580	0.3758	0.2500	0.170
=0.30		1.000	0.645	0.4300	0.287
=0.40			1.000	0.670	0.444
=0.50				1.00	0.67
=0.60					1.000

This makes the rapidity clearly stand out with which the loss (pr) of the active gases rises as soon as the amount of the inert gases in the initial mixture (ti) approaches the concentration (to) of these same gases in the mixture in circulation at the moment of its evacuation by the purging.

To reduce these losses there exist, then, but two means that could, moreover, be foreseen *a priori:* either to utilize gases with very small inert concentrations, or to evacuate the gases only with very high "inert" proportions. Now, one does not always control, as will be seen later on, the reduction at will of the amount of the "inerts" in the industrial gases employed, unless the cost of their preparation is considerably increased; and, on the other hand, in order to raise the inert amounts in the evacuation gases it will be necessary to maintain the gaseous mixture in circulation on the catalyst with a high inert concentration, very near to that of the gases evacuated, since these amounts differ only in the proportion of gases entering into combination.

If, for example, the "inert" concentration in the purging gas is 40% and the amount of the gases that have entered into com-

bination on the catalyst is 20% (a rather high figure) the inert concentration of the gases circulating on the catalyst will not be far from 35%.

Under these conditions, when the amount of the inert gases remains high in the gaseous mixture in circulation on the catalytic agent, the partial pressure of the active gases will be reduced by as much, which will have for an effect, as we have already made apparent, the reduction, proportional to the reduction of the *partial* pressure, of the fraction of the gases combined at each passage over the catalyst, and, consequently, of the output of the apparatus, all other conditions of operation remaining the same.

The impurity of the gaseous mixture employed (particularly in so far as the almost inevitable presence of nitrogen and methane is concerned) has, then, for its effect a greater loss of non-combined active gases (that is to say, of a greater consumption of coal and mechanical energy for the production of the same quantity of organic products), and an increase of the dimensions of the apparatus or an increase of the normal working pressure. It will be expedient, then, in all possible cases, to choose as a raw material a gaseous mixture rich in carbon monoxide and hydrogen and free from methane and especially from nitrogen.

12. GASIFICATION OF COAL IN VIEW OF SYNTHESIS

Since coal contains only carbon and hydrogen (outside of a small percentage of metallic compounds, and of sulphur and nitrogen), it is capable of being transformed almost completely into a mixture of carbon monoxide and hydrogen, a mixture that can itself be transformed into oxygenated organic products by the synthetic reaction that we have just indicated.

For the preparation of a mixture of carbon monoxide and hydrogen starting with coal there exist at the present time numerous processes which have been well worked out and which give a sufficiently high yield. All these processes are, moreover, based in principle on the fundamental reaction of the formation of water gas, i. e., the reduction of water vapor by carbon at a high temperature.

$$C + H_2O = CO + H_2$$

This manufacture of water gas that long ago entered into industrial practice is effected very easily when starting with coke as raw

material; but for several years a new technique, to-day completely perfected, has permitted the substitution, partially or wholly, of run of mine bituminous coals for coke.

It was not without difficulty that this result, for which numerous systems were successively devised, has been reached; among these we shall recall those of Strache, of Rincker, and finally that which appears the most simple and practical, the "Pier Process" of the U. G. I. Contracting Co. of Philadelphia.

To-day there can be considered two methods for the complete gasification of bituminous coals:

The first, allowing the distillation and gasification of the solid residue of the latter almost simultaneously in the self-same apparatus at the exit of which the gases of distillation and the water gas are found mixed;

The second, which consists of effecting first and previously the complete distillation of the coal in special pieces of apparatus (ovens or retorts of current types) and to use only the solid residue of this distillation for the preparation of water gas.

The first method recommends itself by the simplification and economy that are realized in the installations. The gaseous mixture resulting from the simultaneous operations of distillation and of gasification will contain, in general, close to 50% of hydrogen, 30% of carbon monoxide, and 3% of carbonic acid, (say, on the whole, 80% of reactional gases, overlooking the carbonic acid) 6 to 7% of methane and 8 to 10% of nitrogen, with a consumption of 650 to 750 kilograms of crude coal from 1,000 cubic metres of gaseous mixture (or 42 to 43 pounds per thousand cubic feet). Under these conditions the proportion of inert gases is from 15 to 17%, and Table 1, which we gave previously, shows that the proportion of active elements of the initial gas carried along by the purgings will be about 30% (if the circuit of reaction is maintained in the neighborhood of 40% of inert gases). This loss will be reduced to 20% if the proportion of inert gases in the reaction circuit is brought to 50%.

Let us suppose that this latter solution is adopted in spite of its disadvantages as far as yield is concerned: the result will be that there will be utilized effectively for the synthesis only $0.80 \times 0.80 = 0.64$ or 64% of the gross gaseous mixture supplied by the gasification of the coal. If, on the other hand, one admits a loss

of 6% through leakage and handling as in the ammonia synthesis, there will remain approximately only 600 cubic metres of gas really transformed per 1000 cubic metres of gas treated; this corresponds to a consumption of 650 to 700 kilograms of bituminous coal, which leads one to accept, in round numbers, a consumption of 1.10 kilograms of coal per cubic metre of gas that really entered into combination and was transformed into an organic product.

The transformation reaction

$$n\,CO + 2n\,H_2 = Cn\,H_2n - OH + (n-1)\,H_2O$$

will involve consequently the consumption of material as given below according to the kind of alcohol obtained.

TABLE II

MATERIAL CONSUMED PER KILOGRAM OF ALCOHOL OBTAINED

Alcohols		Theoretically pure gas in cubic meters ($nCo+pH_2$)	Practical consumption cubic meters of crude gas	Practical consumption of coal (in kilograms)
Formula	Amount of oxygen %			
$CH_3 - OH$	50%	2.20	3.67	2.42
$C_2H_5 - OH$	35%	3.05	5.10	3.35
$C_3H_7 - OH$	26.7%	3.51	5.85	3.86
$C_4H_9 - OH$	21.6%	3.81	6.33	4.18
$C_5H_{11} - OH$	18.2%	4.00	6.67	4.40
$C_6H_{13} - OH$	15.7%	4.13	6.90	4.54
$C_7H_{15} - OH$	13.8%	4.25	7.10	4.67
$C_{10}H_{21} - OH$	10%	4.44	7.40	4.88
$C_{20}H_{41} - OH$	5.4%	4.73	7.90	5.203

13. UTILIZATION OF THE PURGED GASES

The consumption figures given in the last column of the table above are maximum figures, because they suppose that the gases constituting the purgings remain completely unused, which will generally not be the case. These gases constitute, in fact, an important fraction of the total gas employed since they include the 15% of inert gases and, in addition, 20% of active gases, let us say a minimum (by deducting the mechanical losses), amounting to approximately 30% of the raw material. Taking into account the composition that we have previously conceded for the initial gas,

the composition of the purging gases will be in the neighborhood of the following:

H_2	CO	CO_2	CH_4	N_2
15 to 20%	30 to 35%	0.5 to 1%	23%	37%

This gaseous mixture, having the superior calorific power of nearly 3,500 calories per cubic metre, which is about one-third better than that of water gas, has a value that is far from being negligible as a fuel, and can be utilized as such, if one has use for it.

For want of an application of this kind it seems possible to use the purgings for the synthetic reaction itself in a process analogous to that used by Dr. Bergius for the gas rich in methane which Berginization produces, and which can be produced in the following fashion: on a refractory mass is directed a part of the gas mixed with air. This is brought to a red heat by combustion, and then the rest of the gas mixed with water vapor is passed over it under conditions favoring the reaction:

$$CH_4 + H_2O = CO + 3H_2 + 49 \text{ calories}$$

Each volume of methane of this second fraction of the gas would furnish one volume of carbon monoxide and three volumes of hydrogen. The calculation shows that the combustion of a fourth of the purging gases would furnish the heat necessary for the transformation of the other three-fourths, which, after this treatment, would restore in active gases a volume at least equal to that of the purging gases treated, which would diminish by a third the cost of the coal entered in Table II.

We have not sufficiently perfected this reaction to permit us to regard it as more than a possibility whose realization appears, however, to offer good chances of success.

Or by a still more simple process the purged gases mixed with air can be driven into the gas generator itself during the air flow. The quantity of heat thus generated will realize a corresponding economy in the cost of coal, in the course of this blow-run whose sole aim is to raise the temperature of the fuel before the injection of the steam.

Finally, in addition to all other applications, a normal use of these purged gases can be found in the production, in case of gas engines, of a part of the mechanical energy necessary for com-

pression before synthesis. At the rate of 30% of the gross gas and for a calorific power in the neighborhood of 3,500 calories per cubic metre, these gases are capable of furnishing almost 0.3 kilowatt hour per cubic metre of the original gas employed, that is to say, as will be seen further on, about two-fifths of the mechanical energy necessary for the compression.

Be that as it may, the figures of Table II that do not take into account the recovery of the cleansing gases, show that one may anticipate from now on a *maximum* consumption in approximately the proportion of 2.42 kilograms of coal per kilogram of methyl alcohol obtained, a figure that increases rapidly to its double in the production of higher alcohols. It may be said that the transformation of a ton of bituminous coal can supply, at the *minimum,* 400 kilograms of methyl alcohol or 240 kilograms of isobutyl alcohol, quantities that it would be possible to increase by 30% at least with a rational utilization of the cleansing gases.

Let us note that the direct treatment of the bituminous coals in the gas generator brings on the destruction, or the loss, during the period of the blow run, of a part of the tars and benzols arising from the distillation of the coal. The rest of the tars can be condensed in part in the normal cooling apparatus for water gas, and must be completely eliminated (for example, by electrostatic precipitation—Cottrel process) before the gas enters the compression apparatus. As for the benzols existing in the gas, they condense by themselves and without special treatment in the condensers of the compressors in proportion to the elevation of the pressure of the gaseous mixture.

14. Gasification after Preliminary Distillation

Instead of introducing the raw coal directly into the gas generator it can be subjected to a preliminary distillation while collecting separately the gases that result from it and utilizing directly for the alcoholic synthesis only the water gas obtained by the gasification of the residual coke. Under these conditions, and if the coal is distilled at a high temperature, it may be granted that a ton of bituminous coal yields 280 cubic metres of gas and leaves as a residue 700 kilograms of coke. The latter when treated in the gas generator is capable of producing 1,150 cubic metres of water gas (blue watergas) (36.7 lbs. per M) containing about 50% of hydro-

gen, 40% of carbon monoxide, 5% of carbonic acid, and 5% of nitrogen. If this water gas is used directly and solely in the catalysis (to the exclusion of the distillation gas) the amount of inert gases composed exclusively of nitrogen will be only 5%, and according to Table I given previously, the proportion of active gases carried away into the purging gases will be only 8% if the reaction circuit is maintained at 40% inert, and 5.2% if the gases are evacuated only when the amount of the inert shall reach 50% in the reaction circuit. Adopting the first hypothesis and taking account of the fact that this water gas will contain 90% of active gases, the usable proportion of the latter will be $0.90 \times 0.92 = 0.828$ or 82.8% of 1,150 cubic metres of gross gas, or 952 cubic metres per ton of coal employed. In conceding as before a mechanical loss of 6% the quantity of gas that will actually and practically be transformed into alcohols will be about 900 cubic metres per ton of coal employed; that is, the consumption of coal for the same net result will be approximately the same as in the other case, but with a content in inert gases of the gaseous circuit of 40% instead of 50%, i. e., with a productivity of the catalysis apparatus higher by about 20%.

Moreover, the quantity of gas to compress will be considerably less than in the first case on account of the reduction in volume of the purgings, and the comparison of the importance of the latter in the two cases shows that the volume of gas to compress will be diminished by about 23%, hence a notable reduction in the volume of the compressors and in the cost of mechanical energy.

On the other hand, the gas collected in the distillation of the coal, having a normal composition, can be treated and utilized as is generally done, i. e., as domestic or industrial fuel, or else used in one of the methods that we have previously mentioned, to contribute to the reduction of the consumption of coal belonging to the synthesis itself.

From the preceding it would appear that it is preferable, *for the special utilization that we have in view,* to distill the bituminous coal before gasifying it, or at least, to collect separately the distillation gases, charged with gaseous hydrocarbons. This distillation can be performed at high or low temperature, provided that the solid residue obtained which is to serve for the production of the gas for the synthesis itself will form but very small quantities of

gaseous hydrocarbons (lower than 1%) in the course of the treatment by water vapor.

The preliminary distillation involves, certainly a complication of equipment, if two apparatuses instead of a single one are used. But it appears possible to unite the two units of distillation and gasification into a single apparatus; for example, one can imagine the direct superposition to the gas generator of one of those continuous vertical retorts which have been developed to a large extent in Great Britain, whose base is connected directly with the gas generator. The operation of these vertical retorts is at the present time perfectly adjusted, and for their heating there can be used the sensible heat of the waste gases along with the heat derived from the combination of the purged gas from the catalysis circuit. Likewise, the gas generator of the type "Strache" could be easily modified to collect separately the gases of distillation and gasification.

15. Distillation of Coal under Pressure

As far as the preliminary distillation of bituminous coals before their gasification is concerned, we shall point out here a peculiarity that we have verified and that appears interesting. If there is passed over coal of this kind enclosed in a strong container a part of the compressed and hot gases drawn from the catalysis circuit, it is observed that at the temperature of 350°-400° C. the bituminous coal gives up in a few hours a quantity of volatile substances approximately equal to that which the carbonization at a high temperature would take away from it. For example, we treated in this fashion a flaming coal from the Sarre containing 37% of volatile substances. After three hours of the passage of the gases compressed to 200 atmospheres the coal had lost 34% of its weight; the coke obtained was porous but not friable. Carbonized at a high temperature it liberated 18% of volatile substances and constituted an excellent fuel that did not smoke when burned. That would be an advantageous utilization of the *cleansing* gases, which, withdrawn directly from the gaseous circuit at the exit of the catalysis apparatus and compressed at a high temperature, would pass through containers in which coal would have been put whose distillation would be effected without any additional expense for heating.

Thanks to the high pressure of these gases all of the tars, benzols, and ammonia are easily collected by mere cooling. The only difficulty in the carrying out of this process, whose advantages are evident, resides in the construction of strong containers with a system of opening and closing sufficiently rapid for the introduction of the coal and the extraction of the coke.

16. Combination of Alcoholic Synthesis with the Gas Industry

From the practical and industrial point of view, to the exclusion of other special considerations, the industry of the synthesis of alcohols would be placed in the most favorable conditions by associating it with the operation of a plant engaged in the production of coal gas for supplying a large city located in a coal mining district rich in bituminous coal. For example, if this plant were operating under the conditions described for Joliet, Ill., of the Coal Products Manufacturing Company (Cf W. J. Murdock, Proc. Amer. Gas Assoc. (1924), 766-776) that is, by a series of eight operations of gasification, after which takes place the charging of 2,200 lbs. of coal, each operation comprising two minutes for the air blast (blow run), 2.75 minutes for the injection of steam (50% from below and 50% from the top), and 0.25 minutes of purging. The gas intended for the catalytic synthesis would be withdrawn only during the last three operations, and only during the period of the steam injection into the top of the gas generator, which would represent 12 to 15% of the total production. There would thus likely be obtained a gas containing but very little methane and nitrogen, (See L. J. Willien, Proc. Am. Gas Assoc., 1925) and one particularly suited for synthesis. As for the purging gases of the synthesis apparatus, they would be returned to the gas generator during the early part of the steam blast and would restore to the gas production their high caloric power.

Thus one would arrive at a very economical production that would correspond, according to our calculations, to a net consumption of gas of 2.5 cubic metres per kilogram of pure methyl alcohol and 4.2 cubic metres per kilogram of isobutyl alcohol, which represents a net consumption of raw coal that does not exceed 2 kilograms per kilogram of methyl alcohol and 3 kilograms per kilogram

of isobutyl alcohol. At the same time the cost of the original plant would be considerably reduced. The synthesis of alcohols appears, then, from this point of view, to be an adjunct to the manufacture of gas.

17. Diversity of the Products of Synthesis

We have said that according to the nature of the catalytic agent alcoholic synthesis could furnish a whole series of organic products. Of these latter we shall give the nomenclature as it was indicated by Dr. A. Mittasch of the Badische Anilin-und Sodafabrik (Berichte, 59 (1926), 13-26) in a table that we reproduce below:

$CO + H_2$
CH_2O (?)
$CH_3—OH$ (methyl alcohol)

1. *Alcohols:* (Ethyl alcohol); n. Propyl alcohol (b. p. 97°C.); Isobutyl alcohol (b. p. 108°C.); Amyl alcohol (b. p. 128°C.); Hexyl alcohol (b. p. 148°C.); Heptyl alcohol (b. p. 160°-165°); Octyl alcohol (b. p. 180°); and higher alcohols.

2. *Acids (free or combined):* Formic, Acetic, Propionic, Isobutyric, Valeric, Caproic, and higher acids.

3. *Ethers and Esters:* Dimethyl ether, Methylformate and others.

4. *Aldehydes and Ketones:* Isobutyric aldehyde, Acetone, Methyl ethyl ketone.

5. *Hydrocarbons:* Liquid hydrocarbons of the most diverse kinds (b. p. from 20°C. to 300°C.).

6. *Cyclic Compounds:*

The only one of these compounds that we were able as far as we are concerned, to obtain in the pure state independently of all the others, by catalytic action alone (that is to say without accessory transformation) is methyl alcohol, which can be obtained in a state of great purity and with the theoretical yield corresponding to one of the reactions:

$$CO + 2H_2 = CH_3 — OH$$
$$CO_2 + 3H_2 = CH_3 — OH + H_2O$$

on condition of observing certain precautions with reference to the temperature, the purity of the gas, and the composition of the catalytic agent.

We obtained the other products enumerated above only in the mixed state into which methyl alcohol always entered in consid-

erable proportions; the isobutyl alcohol may reach an amount of 10 to 12%, the latter being always accompanied by less volatile products in variable proportions, whose separation, however, was easily brought about by simple fractional distillation.

We have not yet succeeded, and we know not whether it is possible, to find catalytic agents whose selective action would permit the preparation (apart from methyl alcohol) of one of the other alcohols to the exclusion of all others, although it was verified that the use of certain catalytic agents increases considerably the proportion of certain particular products (isobutyric acid, for example) at the expense of the others.

But a circumstance that may be interesting from an industrial point of view is that the methyl alcohol itself is capable of serving as a raw material for the preparation of other alcohols. In fact, if vapors of methyl alcohol are passed over certain catalytic agents, it is discovered that the complex product obtained contains practically the same proportion of higher alcohols as when water gas is made to react on the same catalytic agent. This circumstance permits the re-using of the methyl alcohol obtained in the reaction and separated by fractional distillation in the production of an additional quantity of higher alcohols, and, consequently, obtaining exclusively these latter as the final product of the reaction. Thus an over-production of methyl alcohol can be avoided in case one should wish to manufacture considerable amounts of higher alcohols and one can even use the methyl alcohol from the distillation of wood in the production of other organic compounds.

18. Methyl Alcohol and Formaldehyde

Methyl alcohol, and its direct derivative, formaldehyde, constitute already, in spite of their limited production and high price, products of prime importance for chemical manufacture. The development that the use of formaldehyde has taken in the production of synthetic resins of the "Bakelite" class is well known. This use is destined, in our opinion, to develop considerably more if only the price of formaldehyde is lowered a great deal, and to extend to other chemical operations. Formaldehyde constitutes, in fact, according to a remark that was made by Professor Guyot (France), the smallest oxygenated organic molecule, and owes to this fact, probably, its very marked properties as a condensation

agent for the other molecules and for its own properties that render it easy to prepare from it products of the sugar family having a similar percentage composition.

Now the process of the catalytic synthesis of methyl alcohol starting with carbon monoxide permits obtaining formaldehyde under conditions particularly interesting from the point of view of economy. It is known, in fact, since the time of the studies of Sabatier and Senderens that are no longer new, that it is possible to prepare formaldehyde by merely passing the vapor of methyl alcohol over reduced copper maintained at a temperature of 200°C. according to the following reaction:

$$CH_3OH = CH_2O + H_2$$

That is, with separation of a volume of hydrogen which, in industrial manufacturing, can be used again in the catalysis circuit under pressure and contribute to the formation of a new quantity of methyl alcohol, instead of being burned in the process now in use for the manufacture of formaldehyde. In proceeding as we have just indicated, one would arrive at obtaining formaldehyde at the same price, if not lower, than that of methyl alcohol, and this circumstance is of such a nature that its application can be developed considerably.

19. Isobutyl and Amyl Alcohols, Ketones and Other Products

Isobutyl and amyl alcohols already have a good market as solvents in the varnish industry, whose development is very rapid. The case is the same with ketones.

The other alcohols are suited for analogous uses. Moreover, each of them can be changed easily into the corresponding aldehyde.

In the same way, the acids (of which several can be used directly, either in combination with cellulose, or for the tanning of leathers) can be converted easily into the corresponding ketones.

We also found in the products boiling at a high temperature considerable quantities of products of the terpineol family and it has already been pointed out (French patent No. 586,031 of September 18, 1924, Badische Anilin-und Sodafabrik) that by condensation of the parts boiling at low temperatures, products of the alcoholic synthesis, there were obtained chemical compounds with

properties analogous to those of oil of turpentine, and by condensation of portions boiling at a high temperature, remarkable solvents of resins and of nitrocellulose.

20. Liquid Fuels

Let us point out that those products of alcoholic synthesis that would not find an immediate market in chemical manufacture constitute by themselves excellent liquid fuels, whose value in this capacity exceeds notably that of the coal consumed to produce them to such a degree that the difference can, in certain cases, cover the cost of production.

We are not among those who believe that the liquid products of this kind, extracted artificially from coal, can under normal conditions enter into commercial competition with the natural liquid fuels extracted from petroleum by mere distillation. We consider that the use of alcohols as fuels, or, in general, that of oxygenated organic compounds, constitutes, in principle, a sort of "degradation" with respect to more noble and advantageous uses that these products ought to find in chemical manufacture, and that they ought to be considered for fuel only when they cannot be utilized in any other direction.

However, there are economic or political circumstances in which such utilization may be either imposed temporarily or practiced as a make-shift for the sale of by-products, made as a matter of necessity along with other more valuable products, and for which a market must be found. This is, as a matter of fact, the case with benzols, by-products of the manufacture of coke and gas, that are used at the same time as raw materials for chemical manufacture and as liquid fuels for automobile engines.

It is in this same capacity as by-products that certain alcohols, obtained simultaneously with others, can be sold as fuels. From this point of view it may be pointed out that methyl alcohol itself, in spite of its small calorific power, is a liquid fuel capable of a satisfactory use in automobile engines. If it is mixed with higher alcohols that restore its calorific power it may even compete with gasoline.

On the other hand, the higher alcohols may be easily dehydrated by catalysis on alumina and furnish the corresponding hy-

drocarbons (hexane, heptane, octane, etc.) that make up the best elements of commercial gasoline. It is by a method of this kind that Professor Franz Fischer prepared a product that he called "Synthine" which brings results, when used in engines, equal to those produced by gasoline.

In this respect, the process of the synthesis of alcohols starting with bituminous coals can be considered, in fact, as an industrial process for the liquefaction of coal and its transformation into a liquid fuel. It would be easy to show that from this point of view it can be compared advantageously with the process of the direct hydrogenation of coal.

21. Cost of Production of Synthetic Alcohols

The development that the future reserves for the industrial manufacture of these products will be, evidently, so much the more rapid and vast, the lower the cost of production. Now, of the original elements that enter into their composition it does not seem that carbon could be derived from a cheaper raw material than bituminous coal, nor that hydrogen (save in some special cases in which it constitutes a by-product that will rarely be very abundant) could be produced more economically than by the decomposition of water vapor on coal. The yield of gas generators is the subject of numerous studies and can be increased by the more complete utilization of the perceptible and latent heat of blast gases.

Among the other elements of the cost of production compression involves an important consumption of mechanical energy that can be evaluated (for a working pressure of 850 atmospheres) at a half of a kilowatt hour (½ kw. h.) per cubic metre of gross gas treated. The accessory services (manufacture of the gas, electric heating of the catalysis tubes, etc.) certainly do not represent more than half of this figure, so that one would have to face an expense of 2.2 to 2.8 kilowatt hours per kilogram of methyl alcohol obtained and from 3.70 to 4.80 kilowatt hours (per kilogram of isobutyl alcohol) according to the purity of the gas employed. This compression and the expense of mechanical energy that it involves constitute one of the special charges of the process. It corresponds, on the contrary, to a considerable specific productivity of the trans-

formation apparatus, and to an automatic separation of the reaction products.

The operation of the synthesis apparatus properly speaking (compressors and autoclaves of catalysis) require but relatively little manual labor, since it is a question of scarcely anything else but supervision. It may descend to relatively low figures if a considerable production is concentrated in one plant with powerful machinery equipped with devices for automatic control, which would generally be the case. By comparison with the experience with ammonia synthesis apparatus, it seems that the expenses for labor can be evaluated on the basis of two days of labor per 3,000 cubic metres of gross gas employed (excluding the labor for the manufacture of the gas).

The expenses for up-keep and repair vary very much according to the perfection of the equipment used. It is chiefly the compressors on the one hand, and the valves and joints on the other hand, that constitute the chief elements of expenses of this kind. These compressors (for pressures above 300 atmospheres) are of a relatively recent use and the troubles experienced by certain plants in their operation must be considered as being but temporary. For our part, we know of plants in which compressors operating at 800 atmospheres function in a continuous fashion for entire months without needing any repairs. The joints exposed to high pressure, if they are properly constructed, do not require more repair than the joints of steam pipes in current use. We estimate that the annual expense of up-keep can be kept at 5% of the value of the apparatus.

As to the first cost it is generally considered as being rather high, and it is certain that at the present time the construction of apparatus for the compression of gases at very high pressures, and of other apparatus for their handling and for catalysis, seem very costly, especially because the few specialized manufacturers collect on the first apparatus ordered rather high charges for design and development. But the development of the synthetic ammonia industry permits the technology of high pressures to improve continuously, and, on the other hand the returns on this apparatus are good, so that its amortization takes place quickly. It is very difficult to give figures on this subject, for the cost of construction

varies considerably from country to country. We can simply say that in France, at the present time, the equipment necessary for a production of 20 tons of methyl alcohol per day would likely not exceed 400,000 to 500,000 dollars. In the United States the cost would, no doubt, be quite higher.

From the above facts it is easy to deduce the total cost according to the stress that will be put on amortization, general expenses, as well as the value of the coal. According to our opinion the total cost price of synthetic methyl alcohol under present conditions in the United States ought not to exceed 20 cents a gallon, and for other alcohols a figure proportional to the number of cubic metres of gas consumed as it was given by Table II above, in relation to that corresponding to methyl alcohol.

22. Future of Synthetic Products Derived from Coal

Synthetic products derived from fossil coal with the aid of mechanical energy supplied by the combustion of coal or by waterfalls have always succeeded in supplanting products derived from the present periodical vegetation. It is thus that artificial alizarin has replaced the extract of madder, that synthetic indigo has been substituted for indigo (from plants), synthetic acetic acid for acetic acid resulting from fermentation. If synthetic camphor has not yet been able to compete with natural camphor, it is, in our opinion, because it depends on a vegetable raw material. The success of the substitution of an artificial technical product derived from coal for the corresponding natural product seems to us to be due to the cheapness of the raw material, to the concentration of its useful elements, to the speed of its transformation in contrast to the high costs of cultivation, and above all, to the crop conditions, on the distribution over large areas, and on the slow growth of the plants. For this last reason and at the same time on account of the technical data brought out previously we think that oxygenated organic products and, in particular, the alcohols obtained when starting with gasified bituminous coal by catalysis under pressure, are destined for a future in industry of no mean importance.

METHYL ALCOHOL AS A MOTOR FUEL

By Paul Dumanois
Chief Engineer of Air Service, France.

The possibilities of the industrial production by synthesis of methyl alcohol lead quite naturally to the study of the conditions under which this substance can be used as a possible substitute for gasoline in internal combustion engines.

A priori, two objections can be made to this fuel: on the one hand, its low calorific value, which is only 5,000 calories instead of 10,600 for gasoline; on the other hand, the possibility, in cases of incomplete combustion, of forming formic aldehyde that is liable to attack the engine parts, especially the valves and piston ends.

We have had the occasion since 1925 to undertake with pure methyl alcohol a certain number of tests with automobile vehicles and have been able to prove that by using anhydrous alcohol the consumption by weight is really about double that in the case of gasoline. This result seemed to us to be in contradiction with those obtained when using a substance of the same family, ethyl alcohol, in case of which the consumption in calories is, everything else being equal, considerably lower than that obtained with gasoline. Moreover, if one takes account of the fact that the combustion in an engine has an efficiency so much the greater the more rapidly the calories are liberated: that is to say, if the carburized mixture is more homogeneous and more volatile than the methyl alcohol with boiling temperature at atmospheric pressure considerably lower than ethyl alcohol (66° instead of 79° C.), the vapor tension is approximately double and better results should follow.

From the analytical study that we have made, we have proved that for volumetric compressions slightly above the usual compressions, that is, of the order of six, the methyl alcohol plainly caused the phenomenon of self-ignition without any species of detonation. We were, therefore, led to examine the question by utilizing the results of our studies relative to the causes that limit in practice the volumetric compression. These phenomena are three in number: on the one hand the phenomenon of detonation, on the other hand the phenomenon of self-ignition

with adiabatic compression, and finally the phenomenon of premature self-ignition at overheated points.

As far as self-ignition by adiabatic compression, properly speaking, is concerned, it does not seem that we should be concerned in any case about this in connection with fuels intended for explosion engines, and with the greatest compressions that can be attained in practice. The phenomenon of detonation occurs, on the contrary, in a constant manner when compressions of the order of five are exceeded, when hydrocarbons derived from petroleum are used, with the exception, however, of the aromatic hydrocarbons.

Finally, self-ignition at overheated parts is the function not only of the fuel considered, but also of the construction arrangements of the motor.

Detonation can be eliminated easily by the anti-detonating substances that we have studied in France, of which the most active is tetraethyl lead whose industrial manufacture Thomas Midgeley has perfected.

As we have shown elsewhere, similar results may be arrived at without anti-detonating substances, by modifying the form of the combustion chamber to bring about local section size increase causing the extinction of the explosive wave, by rendering impossible adiabatic compression when it arrives at that level.

As far as self-ignition is concerned, it can be prevented by mixing with the fuel a substance having a high vaporization heat or having itself special resistance properties toward this phenomenon, and which substance delays, from the fact of its mixture, the temperature at which this phenomenon occurs.

This being the case, a motor fuel that would cause, in case of a compression slightly above the usual compression, one of the phenomena considered above, will have a combustion so much the more irregular with the usual compression, the nearer the conditions of operation, resulting either from temperature increase or from diminution of the usual speed of rotation in high gear, will bring it to a state where the phenomenon occurs.

It is thus that in the course of tests carried out with aviation motors with mixtures of ethyl alcohol and gasoline from petroleum we ascertained that a motor fuel containing 90% gasoline and 10% anhydrous ethyl alcohol, having a calorific power of 10,100 calories per kilogram,

produced for the same consumption by weight a power slightly above that realized with pure gasoline having a calorific strength of 10,600 calories per kilogram, which clearly indicates a better yield in calories. This result has been attributed by us to the fact that ethyl alcohol delays at the same time the detonation limit and self-ignition at overheated points.

If our theories are exact the phenomenon must be still more noticeable with methyl alcohol, which, as we have said, is more volatile than ethyl alcohol and at ordinary temperature has a double vapor tension, provided, however, that the limit of self-ignition be sufficiently delayed.

It is thus that we were able to demonstrate the following with a motor fuel containing 70% of anhydrous methyl alcohol having a calorific power of 6,120 calories per kilogram, a density of 0.8, utilized in a 10 H.P. Citroen standard model automobile in service since 1921, and weighing, when ready for the road, 1270 kilograms. This automobile consumes each 100 kilometres 9.8 litres of gasoline with a calorific power of 10,600 calories, and attains 80 kilometres an hour with difficulty with this fuel.

In a run of 1000 kilometres made last September, 6 to 14, in the course of the races for the testing of national motor fuels organized by the Automobile Club of France, and whose results were checked, there were consumed with the methyl alcohol 12.5 litres of fuel and the speed, maintained almost constantly above 70 kilometres an hour, could have been carried beyond 90 kilometres an hour. Under these conditions the saving in calories in comparison with gasoline amounts to 15%.

During this test, moreover, an immediate verification of the best utilization of calories was given by the temperature of the water in the radiator, which was considerably lower than in case of gasoline. Thus with an atmospheric temperature above 30° it was possible to cover, at speeds between 60 and 80 kilometres per hour, without ventilation, a distance of 105 kilometres without the temperature of the radiator water exceeding 75°.

Moreover, the operation is considerably more flexible than with gasoline. Only exceptionally did the speed have to be changed. Grades were climbed with the throttle wide open without the least knocking,

at the speed of 15 kilometres per hour. The motor gave, at this time, the impression of a steam engine.

As far as the attack on the motor parts is concerned, a complete examination of the motor was made after the race. No trace of oxidation was found either on the valve bearings or on the aluminum piston ends. As to the fouling of the motor, it was practically nil; the spark-plugs, in particular, looked like new.

If one takes into account the fact that the fuel in question, apart from the large proportion of methyl alcohol that it contains, includes only products derived from coal, it is possible to conceive under these conditions when starting out with the latter, the successful manufacture of a fuel for automobile engines that offers a safety of operation and a convenience of use at least equivalent to that given by the best gasoline with a saving of calories in respect to the latter.

COAL AND ITS MINERAL MATTER

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A comprehensive survey of the fuel question as it presents itself today, and of the fuel problems, major and minor, required to be solved in the future is a task not lightly to be approached even by an important and representative gathering such as this Conference. The individual cannot do more than address himself to closely circumscribed areas in the vast field of the science and technology of fuel, though in dealing with such limited phases it is essential for him to consider their bearing upon the problems as a whole. The fuel philosopher, who may permit himself to generalize more readily than the technical piece worker, would not admit any difference in principle between various forms of fuel, whether they be solid, liquid or gaseous, whether coal, peat, wood, straw, oil, gasoline, alcohol or gas. He would lump together under one heading the whole range of combustible matter from high grade anthracite down to dried animal excretions, such as the dung of cows, used by the trekking Boer in South Africa, or that of yaks, burned by the Tibetan tiller of the soil at the foot of the Himalayas. He would include our foods, which by the rule of modern dietetics are evaluated in calories and not by their effect on the palate. To our philosopher all forms of fuel would signify merely stages in the energy cycle in which the synthesis of organic matter from carbon dioxide and water alternates with its resolution by combustion of the fuels thus produced into the same compounds.

The practical fuel technologist is in the less enviable position of having to discriminate clearly between various types of fuels, determine their composition, study their behavior under working conditions, refine them and devise suitable apparatus or plant for their efficient utilization. To him the differences between various forms of fuel and even variations in their quality are very apparent, and his task of

satisfying the artificial heat requirements of modern civilized life is complicated by geographical, economic and commercial considerations and technical limitations.

There are few other, if any, regions on this globe on which Nature has lavished so rich a choice of fuels as on this State of Pennsylvania, where large supplies of coal, oil and natural gas are found in close proximity.

Given the choice between these three forms of fuel we find that there is no difference in principle, though some difference in degree, between the mode of burning gaseous and liquid combustibles. Both represent states of matter which lend themselves to forming intimate mixtures with the oxygen of the air, and both are capable of complete conversion into carbon dioxide and water without leaving any residue. It is not so with solid fuels. True, good progress has been made during the last decade with burning powdered coal, a form in which it vies in efficiency with atomized oil or gas, but the distinguishing feature is that the ordinary solid fuels upon combustion leave a solid, incombustible residue, i. e., ash.

If it were not for the dead weight of their ash content, there is no reason why solid fuels should not give even higher combustion efficiencies than liquid and gaseous fuels. Moreover, the ash-forming matter in coal, our principal solid fuel, affects its utilization in a number of other ways than in direct combustion, and it seems, therefore, important to devote more attention to the study of coal-ash, valueless though it may be in itself, than it has received in the past.

In order to appreciate the significance of mineral matter on the utilization of coal, its incidence, composition and distribution, the manner of its occurrence during coal formation and the mechanism of coal formation itself must be closely examined. The key-note of the work done during recent years in the investigation of mineral matter is the characteristic association of certain inorganic compounds with each of the three or four principal groups of coal components. If the sub-division of banded bituminous coal proposed by Stopes[1] and used by the majority of English coal research workers, into fusain, clarain, vitrain and durain is adopted, an examination of the ash of the four ingredients from one coal reveals considerable differences, both in amount and composition. The ash percentages obtained from the first

[1] Stopes, Proc. Roy. Soc., 1919, B90, 470.

coal examined, Thick Seam, Hamstead Colliery, South Staffordshire, were

	Ash
Fusain	15.59 per cent
Durain	6.26 per cent
Clarain	1.22 per cent
Vitrain	1.11 per cent

The four ashes showed remarkable differences in color and physical structure, fusain ash being dark brownish grey, durain ash pale grey or white, clarain ash reddish-brown biscuit, and vitrain ash pale biscuit color. The qualitative characteristics are explained by the quantitative analysis recorded in Table 1.

TABLE I.

FUSAIN

	Soluble in water. Per cent.	Soluble in HCl. Per cent.	Insoluble in HCl. Per cent.	Total Per cent.
SiO_2	Nil	0.78	8.06	8.84
Al_2O_3	0.19	8.33	4.06	8.66
Fe_2O_3				3.37
MnO				0.51
TiO_2				0.04
CaO	10.03	46.64	0.33	57.00
MgO	0.41	0.89	Nil	1.30
Na_2O	0.65	2.59	....	3.24
K_2O	0.14	0.53	....	0.67
SO_3	4.71	9.17	0.77	14.65
P_2O_4	....	....	....	....
CO_2	0.53	2.45 diff	....	2.98
Total	16.66	71.38	13.22	101.26
Total by direct weighing	16.57	71.38	12.05	100.00

DURAIN

	Soluble in water. Per cent.	Soluble in HCl. Per cent.	Insoluble in HCl. Per cent.	Total Per cent.
SiO_2	Trace	1.46	49.08	50.54
Al_2O_3				42.34
Fe_2O_3				1.36
MnO	Trace	19.94	24.20	Nil
TiO_2				0.44
CaO	1.47	1.85	0.37	3.69
MgO	Nil	Nil	Nil	Nil
Na_2O	Nil	Nil	Nil	Nil
K_2O	Nil	Nil	Nil	Nil
SO_3	2.10	0.98	0.15	3.23
P_2O_3	....	....	....	....
Total	3.57	24.23	73.80	101.60
Total by direct weighing	3.48	23.81	72.71	100.00

CLARAIN

	Soluble in water. Per cent.	Soluble in HCl. Per cent.	Insoluble in HCl. Per cent.	Total. Per cent.
SiO_2	.012	0.96	8.36	9.44
Al_2O_3				16.58
Fe_2O_3				3.51
MnO				0.23
TiO_2				0.50
CaO	10.50	1.94	0.54	12.98
MgO	9.20	1.32	Nil	10.52
Na_2O	13.76	1.95	....	15.71
K_2O	Nil	Nil	....	....
SO_3	31.73	0.45	....	32.18
P_2O_4	Nil	0.01	Nil	0.01
Total	65.41	19.29	16.76	101.46
Total by direct weighing	65.24	17.86	16.90	100.00

VITRAIN

	Soluble in water. Per cent.	Soluble in HCl. Per cent.	Insoluble in HCl. Per cent.	Total. Per cent.
SiO_2	Trace	0.76	5.32	6.08
Al_2O_3				15.49
Fe_2O_3				3.09
MnO	3.11	13.44	2.40	0.13
TiO_2				0.24
CaO	12.42	2.46	0.34	15.22
MgO	1.04	0.83	Nil	1.87
Na_2O	16.12	1.55	....	17.67
K_2O	0.20	Nil	....	0.20
SO_3	28.62	1.49	0.78	30.39
P_2O_4	....	....	....	Trace
CO_2	6.69	....	....	6.69
Total	68.20	20.53	8.84	97.57
Total by direct weighing	69.52	20.46	10.02	100.00

The general picture presented by these analyses has been found to be shown by quite a number of other English coals examined and the conclusions drawn therefrom have been confirmed. These are, that the ashes from clarain and vitrain with their high percentage of water-soluble and low acid-insoluble compounds, represent the original plant ash or what is left of it; that the ash of durain, three-quarters of which is insoluble in hydrochloric acid, is clay substance, whilst the composition of fusain ash indicates its derivation

from the carbonates and other salts of water diffused into the decomposing plant remains forming this component, or adsorbed by it after fusainization. The argillaceous character of durain ash has been definitely proved[2] by its alumina: silica ratio which is equal to that of pure clay substance, kaolinite (Al_2O_3: SiO_2=0.85); thus the possibility that the bulk of its alumina content is derived from the lycopodia originally contained in its raw material which are known to be rich in this compound, is disproved.

The system proposed by Stopes of sub-dividing banded bituminous coal into fusain, durain, clarain and vitrain is descriptive of these materials and hence based on a lithological foundation, whilst the terminology of R. Thiessen, widely adopted in America, who divides coal components other than fusain into attritus and anthraxylon, tends to indicate the raw material from which the various layers were formed, and the physical conditions under which it was deposited. With few qualifications it may be said that anthraxylon covers both clarain and vitrain, whilst attritus is identical with durain. The microscopic findings which the term attritus is meant to express, viz., that the material is the petrified product of an intimate mixture of comminuted plant remains or small plant entities and detrital mineral matter, such as clay, is confirmed by the chemical analysis of ash of durain, which must be regarded as owing its origin to the simultaneous deposition of plant débris and clay mud from suspension in water.

This seemingly academic consideration of the petrological and paleo-botanical character of durain has an eminently practical bearing, inasmuch as it explains the difficulties experienced in the washing of many coals by the ordinary methods, and particularly in the removal of the mineral impurities from "bone" coal, which is rich in durain.

For practical purposes clarain and vitrain may be grouped and considered together, particularly since in vitrain, which on the strength of transparent sections had originally been regarded devoid of morphological structure, cellular plant structure, though much obliterated, has been discovered[3] by examining polished surfaces in reflected light.

[2] Lessing, Trans. Chem. Soc., 1920, 118, 264.

[3] Seyler, Fuel, 1923, 2, 217; 1925, 4, 56—Marjorie M. Evans, Trans. Inst. Min. Eng. 1926, 71, 463.

The clarain-vitrain fraction (in which clarain usually preponderates) is that portion of coal having pronounced coking properties, whilst a large durain content is indicative of a non-coking or feebly-coking fuel. Whether this disparity in coking propensities is, at least in part, due to differences in the ash percentage and in the chemical character of the ashes remains as yet an open question; but it will be shown later on that these factors influence the coking properties to a degree not generally realized.

Fusain, which is present in British coal to the extent of approximately 5 per cent, contains widely varying percentages of ash whose composition indicates that it is, in the main, the residue of water which percolated the coal seam towards the final stages of coal formation, or after fusainization had made some plant remains sufficiently porous to adsorb the salts dissolved in this water. Fusain ash contains a large proportion of carbonates in which either lime or iron may predominate.

The mineral matter contained in the four compounds forming the actual coal accounts for a comparatively small portion of ash found in commercial coal as mined or marketed, amounting to about 3% or less.

By far the larger proportion of this ash is derived from its impurities or accessories. These are, firstly, the inorganic compound filling the cleat and partings of a coal seam. They consist mainly of the carbonates of lime or iron and may assume the crystalline structure of calcite or its substituted forms (ankerites). These minerals, like the infiltration in fusain, are due to the dissociation of calcium or ferrous hydrogen carbonate from water. They also comprise, as does fusain, some insoluble matter which is to be regarded as clay filtered out or precipitated from suspension or colloidal solution in the original water.

The bulk of minerals contributing to the total ash in coal consists of fragments of rock from floor and roof, which get into the coal during mining operations, together with those "dirt" bands, as distinct from partings, which cannot be kept separate economically. This, the quantitatively most important portion of the ash, varies in composition with the nature of the deposit above and below each seam, but mostly consists of shale or fire clay, with sandstone in some cases. Another important contributor to coal

ash is pyrite in its various forms. In view of the importance of the sulphides of iron as a source of undesirable sulphur in coal, coke and gas and their possible bearing upon the spontaneous combustion of coal, these minerals have attracted much attention in the literature, a good deal of which is of a speculative and hence controversial character. The experimental evidence available in either direction, i.e., the formation of pyrite (including marcasite, etc.) and its behaviour on oxidation hardly enables us to draw final conclusions; but in view of the latest conception of the mechanism of coal formation there is no need, and indeed no justification, for assuming that the coal magma has ever passed stages of temperature as high as 250° C., which Donath and Vikipiël[4] assume in support of their explanation of pyrite formation by reduction from iron sulphates. The sulphidation of ferrous carbonate[5] furnishes a plausible explanation without recourse to a rise in temperature up to or beyond the initial decomposition point of many coals.

In regard to the part which pyrite plays in the spontaneous combustion of coal the work of Graham[6] and of Sinnatt and Simpkin[7] proves that it is a contributary and sometimes the initiating cause. Moreover, the acid set free in the oxidation of pyrite acts on the carbonates in cleat and partings, disintegrating the mass of coal as previously described[8] and thus accelerates oxidation and self-heating.

A water-soluble inorganic accessory to many bituminous coals is sodium chloride, the presence of which is of importance in coking coals, inasmuch as it is volatile at high temperatures and apt to flux and destroy the oven walls. Its presence in coal which is probably due to the original plant material having been carried by or laid down in salt or brackish water, may have had a more subtle effect on the structure of a coal seam than is indicated by mere mechanical admixture. On applying the principles of colloidal chemistry to the mechanism of coal formation, one would expect that the ulmins which form

[4] Donath and Vikipiël, Brennstoff-Chemie, 1926, 7, 153.
[5] Lessing, J. Soc. Chem. Ind., 1925, 44, 277T.
[6] Graham, Trans. Inst. Min. Eng., 1924, 66, 41, 145; 1925, 69, 413; J. Soc. Chem. Ind., 1924, 43, 79T.
[7] Sinnatt and Simpkin, Lancs. and Ches. Coal Res. Assoc., 1922, Bull. 12.
[8] Lessing, Trans. Inst. Min. Eng., 1923, 64, 294.

the ground mass of the coal substance on the one hand, and the clay substance which makes up the bulk of the ash-forming material, on the other, would show absorption phenomena and would in particular be subject to coagulation by an electrolyte like sodium chloride. It has now been shown by E. McKenzie Taylor[9] that base exchange may take place between clay and absorbed sodium chloride. Moreover, a clay layer thus made alkaline may become impermeable to oxygen and thus effectively seal off the peat or peat-like material underlying it, which henceforth will be decomposed under strictly anaerobic conditions. This interesting theory is fortified by analytical proof that roof shales are usually alkaline, having a pH-value of 8.2 to 9.0. The floors of coal seams examined showed a lower hydrogen-ion concentration, thus proving my contention that soluble organic compounds of an acid character such as ulmic acid, on percolating through lower layers, will leach out bases which may be reprecipitated elsewhere on their downward path, bringing about a redistribution notably of iron and alumina on the lines of the formation of hard-pan[10].

I fear I owe an apology to an assembly of practical fuel technologists for introducing questions of coal formation and constitution; but I am convinced that for a solution of the many technical problems before us a knowledge of these fundamentals is absolutely essential, and they should therefore be considered at every step in winning, preparing and utilizing coal.

Such a study is particularly necessary for an intelligent appreciation of the distribution of mineral matter in coal. It has been shown that every component of the coal substance and every accessory occurring in commercial coal yields a more or less defined amount of ash of a particular chemical composition and hence physical characteristics. It must, however, not be assumed that the ash in each ingredient of the coal mass is evenly distributed or even of entirely uniform composition, for both the ash content and its composition vary within some groups according to the size of particle. From a great number of coals examined on these lines, Table II may serve as an example.

[9] McKenzie Taylor, Fuel, 1926, 5, 195.
[10] Lessing, Roy. Soc. Arts., Cantor Lectures, p. 7.

TABLE II.

Ash in Graded Fractions Contained in Lump-Coal from the Thick Seam, Hamstead Colliery

Screen	Grading test.	Dust.	Clarain-Vitrain.	Durain.	Dirt.
Fractions: Percentage on Entire Sample.					
On 5	5.70	Trace	4.81	0.85	0.04
Through 5 on 10	63.70	Trace	41.84	21.64	0.22
Through 10 on 20	12.90	0.05	7.96	4.84	0.05
Through 20 on 30	6.50	0.03	4.07	2.35	0.05
Through 30	11.00	3.75	4.88	2.27	0.10
Loss on sifting	0.20	.....	.....	.....	.....
	100.00	3.83	63.56	31.95	0.46
Ash: Percentage on Fractions.					
On 5		.....	2.28	5.74	29.64
Through 5 on 10		.....	1.85	4.62	30.57
Through 10 on 20		.....	1.30	4.26	46.02
Through 20 on 30		.....	1.25	4.45	50.42
Through 30		2.98	1.90	5.58	63.19
Ash: Percentage on Entire Sample.					
On 5	0.17	.....	0.11	0.05	0.01
Through 5 on 10	1.84	.....	0.77	1.00	0.07
Through 10 on 20	0.33	.....	0.10	0.21	0.02
Through 20 on 30	0.17	.....	0.05	0.10	0.02
Through 30	0.39	0.11	0.09	0.13	0.06
	2.90	0.11	1.12	1.49	0.18

The principal features shown in the table, great friability of fusain dust, decrease of ash in clarain with decreasing size and increase in its fines (due to fusain particles) the uniformity in durain and increase of ash in dirt with decrease in size, are fairly typical.

COAL, SAMPLING

The lack of homogeneity in the distribution of ash over a quantity of coal causes considerable difficulties in drawing samples from a cargo or consignment. The estimation of ash is probably the most important operation in the examination of coal for commercial purposes. As the

ash percentage varies with the size of lump or particle, and as there is segregation according to size taking place on loading coal or heaping it up, the ideal method of drawing samples would be to grade the bulk by screening, draw samples from each grade, and combine aliquot portions of each grade according to their contribution to the bulk. This method would be economically impossible with large consignments, but is worthy of consideration when dealing with the first bulk sample taken, for its further sampling and preparation for analysis.

Satisfactory sampling of coal presents quite a problem of its own, and in view of the values of coal and the world wide commercial interests involved it seems highly desirable that appropriate methods applicable to the various conditions met with should be adopted by international agreement.

COAL CLEANING

The mineral constituents contained in the four separable coal components may be termed the "inherent" ash and do not exceed 3 per cent in most coals, at any rate in Great Britain. Strictly speaking, that portion of fusain and durain ash which is not derived from the original vegetable raw material should not even be included in the "inherent" ash. The bulk of the ash in commercial coal which may be from 7 to 12 per cent and may rise to 20 per cent in the case of slack or duff consists of the adventitious impurities described before which are grouped together as "dirt."

The major portion of the dirt in coal as brought to the surface is "free"; it consists of particles, not firmly cemented to pure coal substance, though they do, in as far as they consist of carbonaceous shale, contain combustible matter, but largely diluted with mineral substances. The fact that the dirt particles are discrete and are of higher specific gravity than the coal substance, is the foundation of all coal cleaning processes.

The removal of mineral matter from mined coal is the most important step in the preparation of coal for the market, for even its sizing by screening brings about a differentiation in ash percentages, whilst the third operation, the drying of coal, though desirable is not yet practiced to an appreciable extent.

Cleaning processes, other than hand-picking, are applied mainly to the smaller grades in which, on account of the greater fragility and

friability of dirt bands and partings, the ash-forming substances are concentrated. The higher market price which large lumps usually command is mainly due to the guarantee implied by the fact of their remaining unbroken in the course of handling that they are reasonably free of these impurities.

Cleaning Processes

The cleaning processes may be divided into those based entirely on differences in specific gravity and those in which specific surface properties discriminate between coal and dirt.

Based on specific gravity. The bulk of washed coals is prepared in jig washers, built and operated on the principle introduced by Bérard in 1850. A pulsating motion is given to the water in the washbox sufficient to make the coal rise and overflow, but insufficient for floating the specifically heavier dirt which sinks and is drawn off at the bottom.

Water-flow washers make use of the same difference in physical properties, but operate with a continuous flow either in an upward direction, as in the Draper washer, or horizontally as in the Rhéolaveur.

Concentrating tables, well tried in the refining of metalliferous ores, are now used for the washing of coal and some have been introduced into a number of collieries.

With the object of assisting the separation of clean coal and shale the use of a suspension of sand in water was proposed by Chance, whilst Conklin suggested a pulp of magnetite fines in water for the same purpose. The ratio of solid to liquid in the pulp is adjusted by varying the velocity of the current. Both processes involve the separation and recovery of the sand or magnetite respectively from the clean coal and refuse.

Recently endeavors are being made to overcome the complication introduced by the residual moisture left in coal cleaned by wet processes. With this end in view, air has been substituted for water as the carrying medium. In the American Coal Cleaning Corporation's pneumatic separator, exploited in England by the Birtley Iron Co., air is blown from below through a perforated deck of a rocking concentrating table, fitted with riffles of definite depth and inclination, at such a velocity that the coal particles are assisted over the riffles, whilst the

dirt particles are too heavy to jump the obstacles and are moved along the grooves towards a separate discharge shute.

An ingenious method of dry-cleaning is that proposed by Fraser and Yancey[11] in which the separating medium consists of a body of dry sand, maintained in a fluid condition by a continuous stream of compressed air, equalized over the whole cross-section of the vessel by being split up into bubbles on passage through a porous false bottom. A coal-sand mixture overflows, from which the sand is screened out, whilst the refuse sinks through the loosened sand bed and is also screened. In some respects this proposal is similar to the Chance and Conklin processes.

Needless to say that in all these processes based on the difference in specific gravity of coal and mineral impurities the question of particle size plays an important part which is too well known to require further elaboration here.[12]

Based on specific surface. The somewhat indifferent separating effect of existing coal washing plants has led inventors to seek for more positively acting processes.

Froth flotation, which has been used for many years in the concentration of sulphide and other ores, has been applied to coal washing with fair success. The shortcomings are the necessity of dealing with finely ground coal and the difficulty of de-watering the pulp produced, which is enhanced by the film of flotation oil adhering to the particles.

The Trent process in which larger quantities of oil are churned up with the aqueous coal suspension also belongs to the category of processes relying on the difference in surface phenomena between coal and dirt.

The dry cleaning of coal in the spiral separator, being based on specific friction, also comes under this heading.

SCIENTIFIC CONTROL OF COAL WASHING AND CLEANING PROCESSES

Most of the existing washing and cleaning processes and plants labour under the difficulty that they have not been conceived with a full appreciation of the true composition and distribution of mineral matter in coal and that the existing knowledge of physical and colloidal chemistry concerning the phenomena involved is not yet

[11] Amer. Inst. Min. and Met., Feb., 1926.
[12] See Chapman and Mott, Fuel, 1926, 5, 143, 184, 245, 278, 325, 386, 422.

applied to a sufficient extent. The full significance of the colloidal aspect of washery waters is not being grasped by the majority of designers and operators, and intensive research in this direction would lead to greatly enhanced efficiency.

During the last few years, however, greater attention has been given to these points, particularly in the direction of establishing washability curves on the basis of float-and-sink tests, and of radiographic examination.

Need for Clean Coal

The enormous importance of the removal of the bulk of ash-forming substances as its principal preparation for the market cannot any longer fail to be realized.

For the purpose of evidence given before the Royal Commission on the Coal Industry (1925), I have calculated the tonnage of ash contained in the annual coal production of Great Britain. I have arrived at an estimate of 25,000,000 tons of ash, or more than the output of iron ore. The cost of railway transport of this more than useless material is about £4,500,000, which after adding the cost of handling, ash disposal and consequential losses, bring the total to the stupendous figure of from £10,000,000 to £20,000,000 of non-productive expenditure.

The coal consumed by the British carbonizing industries amounts to about 40,000,000 tons in a normal year, divided almost equally between the coking and gas industries. On calculating the average ash percentages of the coals used in these operations we find that the equivalent of 1,200 coke ovens and that of almost the whole carbonizing capacity of the Gas Light & Coke Co., the world's largest gas undertaking, is continuously employed for uselessly heating inert material. I leave it to others to compute the capital cost of this idle plant and the operating and maintenance costs occasioned by the deadweight of the ash.

Similar considerations apply to the coke consuming industries. In blast furnace work the expense entailed by supplying extra fuel to heat the ash, extra limestone to flux it, and further fuel to heat the limestone has been repeatedly calculated.

The heavier limestone charge is mainly required to neutralize the silica and alumina associated with the dirt in coal. The follow-

ing table shows the reduction of these compounds in the washing process to be greater than that of the other ash constituents, and points the way to more drastic cuts of limestone and fuel in the burden of blast furnaces than are considered possible today.

TABLE III.

	Unwashed %	Washed %
Ash in coal	18.01	4.92
Dirt in coal	20.00	5.00
Total SiO_2 in ash	50.25	34.14
Dirt SiO_2 in ash	44.14	18.50
Total SiO_2 in coal	9.05	1.65
Dirt SiO_2 in coal	7.95	0.91
Dirt SiO_2: total SiO_2	87.84	54.18
Total Al_2O_3 in ash	24.54	24.32
Dirt Al_2O_3 in ash	19.71	9.27
Total Al_2O_3 in coal	4.42	1.20
Dirt Al_2O_3 in coal	3.55	0.46
Dirt Al_2O_3: total Al_2O_3	80.32	38.11

Most of the difficulties in connection with boiler and other furnaces are due to the ash, and much ingenuity has been exercised in the provision of plant and mechanism for dealing with this material, the bulk of which should never find its way to the consumer.

In powdered fuel work the inorganic matter is of paramount importance. Its hardness in the pulverizers, its fusibility in the combustion chamber, and its evasiveness in the dust collectors, present constantly recurring problems.

In the liquefaction of coal by hydrogenation, according to Bergius, an undue ash percentage in the coals treated adds enormously to the difficulties of design and maintenance of the high-pressure plant, particularly by the erosion of the inlet and outlet valves of the auto-claves.

THE IMPORTANCE OF ASH COMPOSITION IN THE UTILIZATION OF COAL

The composition and distribution of mineral matter in its relation to the formation, constitution, winning and preparation of coal have already been discussed. It remains to examine the bearing upon the

utilization of coal of these factors as distinct from the total amount contained in it.

In direct combustion processes which absorb by far the greatest bulk of all coal produced, the chemical composition of the ash-forming ingredients may often determine the behavior of the fuel on the grate and its heating efficiency; for on it depends in its turn the fusibility or refractoriness of the ash. Fluxes, i. e., iron, alkaline earths or alkalies, lower the melting point of the ash and produce clinkering and hence clogging of fire bars or producer beds, inclusion of unburnt carbon, and difficulties of air admission to the fuel bed. A low percentage of fluxes avoids these troubles, gives a "clean" fire and thorough aeration of the fuel bed.

The "melting" point of coal ash has been investigated very closely, particularly by Fieldner and his collaborators,[13] who have given special attention to the influence of an oxidizing or reducing atmosphere upon the fusibility test, inasmuch as it affects the melting points of the oxides or silicates of iron.

In view of the difference of ash composition in the four coal components and the extraneous minerals a note of warning should be sounded, that the results of melting point tests must be applied judiciously. For, as a result of the irregular distribution of ash-forming bodies over the mass of coal components and the extraneous minerals, conditions in practice are very different from those in tests on finely ground and homogeneously mixed average samples. Whilst, thus, a slag film of clarain ash or ankerite parting may not lower the fire stability of a lump of durain ash burned to a highly refractory firebrick, the fluxes in an ash of the same mean composition, ground and intimately mixed, would have a much more marked effect on the less fusible portions.

Again, size of particle is of considerable importance, and as it increases clinkering is promoted. The ash from powdered fuel approaches most nearly the condition of the melting point test, at least at the point where it is collected, though while freely suspended in

[13] U. S. Bur. Mines, Bull. 129, Bull. 209, Fuel, 1926, 5, 24.

combustion gases each particle follows the melting point laws fairly strictly.

MINERAL MATTER IN THE CARBONIZING PROCESS

Our knowledge of the behavior of the inorganic compounds in coal during the coking process is very restricted. The reactions under its reducing conditions are bound to differ from those it undergoes in oxidizing combustion. Moreover, some of the compounds formed may react again when the hot coke produced is cooled to ordinary temperature.

An interesting example is the behavior of pyrite observed by Powell,[14] who found that pyrite is decomposed between 300° and 600° C. into ferrous sulphide and free sulphur ($FeS_2 = FeS + S$), and that the ferrous sulphide on slow cooling is completely oxidized according to the equation: $4\ FeS + 3\ O_2 = 2\ Fe_2O_3 + 4\ S$, whilst at least a portion of it remains unoxidized when the coke is quenched rapidly below 500°.

Table IV shows how some of the changes which ash compounds undergo during carbonization can still be traced after incineration of the coke.

INORGANIC COMPOUNDS AS CATALYSTS

The influence of mineral matter on carbonization and combustion which I consider their chemically most important, scientifically most interesting and practically most promising function, is its capacity of directing catalytically the course of thermal decomposition[15], for recognition of the part of catalysts which some inorganic substances play in the reactions involved, met, until quite recently, with most disappointing response from practical gas and coke oven men.

The results of work[16] summarized in Tables V, VI and VII, which in each of the three series was carried out under identical experimental conditions, leaves little room for doubt that some inorganic compounds influence the carbonizing mechanism. The remarkable quantitative variation in the yield of coke, according to the catalyst employed, is equalled if not surpassed by the extra-

[14] Powell, Ind. Eng. Chem., 1921, 13, 33.
[15] Lessing, William Young Memorial Lecture, J. Gas Lighting, 1914, 127, 570.
[16] Lessing, and Banks, J. Chem. Soc., 1924, 1925, 2344.

ordinary differences in physical characteristics of the coke specimens obtained. Further, as is shown by the results obtained with coal, the ratio of solid residue to volatile products can be influenced at will, as can be the properties of both.

Last year some of this work was repeated by Marson and Cobb,[17] to whom I had pointed out the necessity of considering the

TABLE IV.

YORKSHIRE COKING SLACK.
CLARAIN-VITRAIN FRACTION.

	In coal	In coke
Ash % of coal	2.45	2.41
Analysis of—	Ash from coal	Ash from coke
	%	%
Soluble in Water	1.82	1.62
Soluble in HCl	42.54	35.98
Insoluble in HCl	55.64	62.40
Soluble in HCl (including soluble in water)	%	%
SiO_2	0.36	0.42
Al_2O_3	15.69	9.53
Fe_2O_3	22.99	22.83
CaO	0.90	1.52
MgO	0.30	0.27
Na_2O	1.29	0.98
SO_3	0.21	0.65
	41.74	36.20
Insoluble in HCl		
SiO_2	42.16	43.14
Al_2O_3	10.76	18.16
Fe_2O_3	0.80	1.04
CaO	0.24	0.32
MgO	Nil	Trace
	53.96	62.66
Total Ash		
SiO_2	42.52	43.56
Al_2O_3	26.45	27.69
Fe_2O_3	23.79	23.87
CaO	1.14	1.84
MgO	0.30	0.27
Na_2O	1.29	0.98
SO_3	0.21	0.65
	95.70	98.86

[17] Marson and Cobb, Gas J., 1925, 171, 39.

TABLE V.

Influence of Catalysts on the Carbonization of Sugar

Compound added.		Compound formed.		Coke obtained (less "compound"), Gms. per 100 gms. of Sugar.			
Formula	Gms. per 100 gms. of sugar.		Gms. per 100 gms. of sugar.	Wet.	Dry.	Diff.	Mean.
H_2SO_4	0.98	—	nil	18.28	18.74	—0.46	18.51
$MgCl_2$	0.95	MgO	0.40	17.89	16.96	+0.93	17.43
$CuSO_4$	1.60	Cu_2S	1.59	19.11	14.82	+4.29	16.97
$\frac{2}{3}Al_2(SO_4)_3$	2.30	Al_2O_3	0.68	19.33	13.67	+5.68	16.51
$AlCl_3$	1.34	Al_2O_3	0.51	17.41	15.51	+1.90	16.46
$\frac{1}{3}Al_2(SO_4)_3$	1.14	Al_2O_3	0.34	16.43	15.78	+0.65	16.11
$3NH_4Cl$	1.61	—	nil	16.90	15.15	+1.75	16.03
$FeCl_3$	1.62	FeO	0.72	17.02	14.44	+2.58	15.73
$\frac{1}{6}Al_2(SO_4)_3$	0.57	Al_2O_3	0.17	15.95	12.11	+3.84	14.03
$FeSO_4$	1.52	FeS	0.88	14.00	12.46	+1.64	13.23
$\frac{1}{2}FeSO_4$	0.76	FeS	0.44	14.99	10.21	+4.78	12.60
2NaCl	1.17	Na_2CO_3	1.06	12.42	10.79	+1.63	11.61
NH_4Cl	0.53	—	nil	12.33	10.22	+2.11	11.28
$Ni(NO_3)_2$	1.83	NiO	0.76	10.45	11.77	—1.32	11.11
$2KNO_3$	2.02	K_2CO_3	1.38	.....	11.08	?	.....
$Cu(OH)_2$	0.98	Cu_2O	1.43	11.41	10.39	+1.02	10.90
$NaHSO_4$	1.20	Na_2SO_4	0.71	9.97	10.94	—0.97	10.46
Na_2SiO_3	1.22	Na_2SiO_3	1.22	11.00	9.90	+1.10	10.43
Na_2CO_3	1.06	Na_2CO_3	1.06	10.18	10.69	—0.51	10.44
K_2CO_3	1.38	K_2CO_3	1.38	9.08	11.19	—2.11	10.14
2NaOH	0.80	Na_2CO_3	1.06	10.89	9.17	+1.72	10.03
NaCl	0.59	Na_2CO_3	0.53	8.70	10.47	—1.77	9.59
$\frac{1}{2}Al_2O_3$	0.51	Al_2O_3	0.51	9.44	7.45	+1.99	8.45
$MgSO_4$	1.20	MgO	0.40	8.78	7.89	+0.89	8.34
$Al(OH)_3$	0.78	Al_2O_3	0.51	8.09	7.74	+0.35	7.92
$CaCO_3$	1.00	CaO	0.56	8.44	6.92	+1.52	7.88
SiO_2	0.60	SiO_2	0.60	8.26	6.93	+1.33	7.61
$MnSO_4$	1.51	MnO	0.71	8.48	6.76	+1.72	7.61
China clay	2.59	Ign. clay	2.23	8.72	6.16	+2.56	7.44
$(NH_4)_2CO_3$	0.96	—	nil	6.88	7.04	—0.16	6.96
$Fe(OH)_2$	1.07	Fe_2O_3	0.80	8.27	5.53	+2.74	6.90
$\frac{1}{2}Fe_2O_3$	0.80	Fe_2O_3	0.80	7.31	6.40	+0.91	6.85
Untreated	nil	—	nil	6.45	6.48	—0.03	6.46
Na_2SO_4	1.42	Na_2SO_4	1.42	7.11	5.67	+1.44	6.39
FeS	0.88	FeS	0.88	6.07	6.55	—0.48	6.31
$NiCO_3$	1.19	NiO	0.75	7.28	5.26	+2.02	6.27
CaO	0.56	CaO	0.56	6.38	6.11	+0.27	6.25
$\frac{1}{2}(COOH)_2$	0.45	—	nil	5.44	6.44	—1.00	5.94
CuO	0.79	CuO	0.79	6.17	5.35	+0.82	5.76
MgO	0.40	MgO	0.40	5.62	5.26	+0.36	5.44
NiO	0.75	NiO	0.75	5.63	5.02	+0.61	5.33

TABLE VI.

Influence of Catalysts on the Carbonization of Cellulose

Compound added.		Compound formed.		Coke obtained (less "compound"), Gms. per 100 gms. of cellulose.			
Formula	Gms. per 100 gms. of cellulose.		Gms. per 100 gms. of cellulose.	Wet.	Dry.	Diff.	Mean.
H_2SO_4	0.98	—	nil	19.82	20.36	—0.54	20.09
$\frac{2}{3}Al_2(SO_4)_5$	2.30	Al_2O_3	0.68	14.77	13.11	—0.34	14.94
$CuSO_4$	1.60	Cu_2S	1.59	12.68	14.81	—2.13	13.75
$AlCl_3$	1.34	Al_2O_3	0.81	13.07	14.36	—1.29	13.72
$\frac{1}{2}Al_2(SO_4)_3$	1.14	Al_2O_3	0.34	12.80	14.30	—1.50	13.56
Na_2CO_3	1.06	Na_2CO_3	1.06	14.87	12.14	+2.73	13.51
Na_2SiO_3	1.22	Na_2SiO_3	1.22	13.38	13.28	+0.10	13.33
$FeCl_3$	1.62	FeO	0.72	11.78	14.80	—3.02	13.29
2NaOH	0.80	Na_2CO_3	1.06	13.46	12.84	+0.62	13.15
$MgCl_2$	0.95	MgO	0.40	10.83	13.73	—2.90	12.18
NaCl	0.59	Na_2CO_3	0.53	12.21	11.56	+0.65	11.89
$3NH_3Cl$	1.61	—	nil	9.92	13.30	—3.58	11.71
2NaCl	1.17	Na_2CO_3	1.06	12.65	10.64	+2.01	11.65
K_2CO_3	1.38	K_2CO_3	1.38	10.98	11.55	—0.57	11.27
$3KNO_3$	2.02	K_2CO_3	1.38	9.33	12.94	—3.61	11.24
$\frac{1}{2}FeSO_4$	0.76	FeS	0.44	9.64	12.07	—2.43	11.00
$FeSO_4$	1.53	FeS	0.88	9.72	11.92	—2.20	10.82
NH_4Cl	0.53	—	nil	8.44	11.46	—3.02	9.96
$\frac{1}{6}Al_2(SO_4)_3$	0.57	Al_2O_3	0.17	8.37	11.38	—3.01	9.88
CuO	0.79	CuO	0.79	7.79	10.25	—2.46	9.02
$NiCO_2$	1.19	NiO	0.76	8.32	9.50	—1.18	8.91
Na_2SO_4(	1.42	Na_2SO_4	1.42	7.75	9.92	—2.17	8.84
$Fe(OH)_2$	1.07	Fe_2O_3	0.80	8.50	9.06	—0.56	8.78
CaO	0.56	CaO	0.56	8.49	9.04	—0.55	8.77
NiO	0.75	NiO	0.76	8.55	8.82	—0.27	8.69
$Al(CH)_3$	0.78	Al_2O_3	0.51	8.11	9.26	—1.15	8.69
$Ni(NO_3)_3$	1.83	NiO	0.76	8.55	7.07	+1.48	7.81
$\frac{1}{2}Fe_2O_3$	0.80	Fe_2O_3	0.80	9.03	6.11	+2.92	7.57
$Cu(OH)_2$	0.98	Cu_2O	1.43	8.49	6.07	+8.42	7.28
$MgSO_4$	1.20	MgO	0.40	6.72	7.80	—1.08	7.26
China clay	2.59	Ign. clay	2.23	7.88	6.31	+1.37	7.20
$+Al_2O_3$	0.51	Al_2O_3	0.51	6.92	7.24	—1.32	7.08
$NaHSO_4$	1.20	Ha_2SO_4	0.71	5.88	8.19	—2.31	7.04
MgO	0.40	MgO	0.40	5.15	7.74	—2.59	6.99
FeS	0.88	FeS	0.88	7.27	6.61	+0.76	6.89
$MnSO_4$	1.51	MnO	0.71	3.10	8.50	—3.40	6.80
SiO_2	0.60	SiO_2	0.60	6.70	6.25	—0.15	6.78
$(NH_4)_2CO_3$	0.96	—	nil	4.70	8.00	—3.30	6.35
$CaCO_3$	1.00	CaO	0.56	6.20	5.63	+0.57	5.92
Untreated		—	nil	5.60	6.00	—0.40	5.80
$\frac{1}{3}(COOH)_2$	0.45	—	nil	5.23	5.16	+0.07	5.19

composition of the ash in all carbonizing experiments[18], and their results confirmed this view.

They have recently[19] further examined the influence of some catalysts on the physical properties of the coke and particularly on its reactivity to which I had called attention[20], by gasifying it in steam and ascertaining the water gas equilibrium under definite experimental conditions. This work fully confirms the conclusions drawn from the previous investigations.

The catalytic activity of certain ash constituents or additions is not restricted to the carbonizing process at high or low temperature, but it also applies to combustion whether carried to completion, as in industrial or domestic heating practice, or in the form of partial combustion as in gas producers.

The importance of catalysts is not likely to be of less account in the hydrogenation of coal, which is now likely to emerge from the

TABLE VII.

Influence of Catalysts on the Carbonization of Coal at 900°

CLARAIN AND VITRAIN FROM DALTON MAIN.

Through 30-mesh sieve. HCl-extracted.

	Coke less compd. formed.	Retort carbon.	Tar.	Gas (c. c. per gm.).	Coke+ retort carbon.	Tar+ retort carbon.
	%	%	%		%	%
$FeCl_3$	65.72	1.32	17.59	254	67.04	18.91
H_2SO_4	64.33	1.07	18.15	262	65.40	19.22
$FeSO_4$	64.04	1.94	20.85	256	65.98	22.79
Na_2SiO_3	63.69	1.09	20.12	249	64.78	21.21
Na_2CO_3	63.50	1.74	20.37	245	65.24	22.11
SiO_2	63.34	1.51	21.28	252	64.85	22.79
Al_2O_3	62.92	1.95	22.13	243	64.87	24.08
K_2CO_3	62.77	1.41	21.69	244	64.18	23.10
2NaCl	62.28	1.82	20.76	235	64.10	22.58
$\frac{1}{2}Fe_2O_3$	62.23	3.34	24.05	245	65.57	27.39
CaO	61.08	3.42	20.20	253	64.50	23.62
MgO	60.94	3.57	22.05	248	64.51	25.62
$(COONa)_2$	59.92	3.69	19.73	258	63.61	23.42
Na_2SO_4	57.62	5.34	26.17	269	62.96	31.51
Untreated	53.68	8.48	29.02	255	62.16	37.50

[18] Lessing, Gas J., 1921, 156, 240.
[19] Marson and Cobb, Gas J., 1926, 175, 882.
[20] Lessing, J. Soc. Chem. Ind., 1925, 44, 345T; Cantor Lectures, 1925, p. 46.

experimental stage to become a practical, commercial process. In the process as proposed by Bergius some iron oxide is added to the coal charges, and I venture to suggest that its function goes beyond that attributed to it, viz., to combine with sulphur. Bergius[21] recognizes the influence of the inorganic constituents of coal on its liquefaction and his suggestion deserves attention that their study will be advanced by the examination of the solid residue obtained in his process, which consists to a large extent of the mineral compounds unaffected by high temperature reactions.

The vital importance of catalysts in the synthesis of liquid hydrocarbons and alcohols, according to the processes of the Badische Company, Franz Fischer, Patart and Audibert, though not dealing with coal but its gaseous products need only be mentioned to make us realize that we may expect quite astounding developments in this new field of fuel technology.

We are on the threshold of a new era in the utilization of coal, and the possibility foreshadowed of refining the natural product, of concentrating its intrinsic value and of applying it in novel ways, is rapidly changing our conception of its potentialities and makes one realize that we are witnessing the beginning of a revolution in the application of our principal source of energy.

DISCUSSION

HUGH S. TAYLOR.* Mr. Chairman and members of the coal conference, I have been casting about in my own mind to find a reason why a mere physical chemist should be intruded upon a group of fuel technologists, and I can only conclude that my duty is to offer either congratulations or condolences on the fact that the catalyst has at last invaded the field of fuel. Someone once said that catalysis is something which accelerates the rate of chemical reactions and the decay of chemical industries.

It seems to me necessary to take into consideration this function of the catalyst in the utilization of fuels. Anyone can convince themselves of the existence of catalysis by a simple if somewhat quixotic experiment. All that is needed is to substitute for ordinary coke in the water gas generator some of the retort carbon of which we have just heard something from Dr. Lessing. If you do so, you will find that some of the reactions which ordinarily occur in the water gas generator are to a very large extent missing, and the composition of the gases

[21] Z. Ver. Deutsch. Ing., 1925, 69, 1313, 1359.
*Professor of Chemistry, Princeton University.

which you obtain will be in no sense similar to those you obtain from coke. The carbon dioxide content of the gas will be vanishingly small as contrasted with the 3-6% normally obtaining in blue water gas from coke. There you have a somewhat practical demonstration of the function of the mineral constituents of the coal in gasification by steaming. These mineral constituents promote the water-gas equilibrium. Now, as the re-activity of carbon and steam is a very much more ready reaction than the interaction of hydrogen with carbon, it seems to me that it must be expected that the interaction of hydrogen with coal and the constituents of coal must of necessity be influenced by the judicious use of catalytic agents. I gathered that Dr. Bergius is not yet ready to believe that catalytic forces are operative in the process of Berginization. From the theoretical standpoint entirely, however, it seems to me quite to be expected that the interaction of hydrogen with carbonaceous materials must be modified by the presence of catalytic reagents. I see ahead quite a considerable field of investigative work to prove or disprove that point of view. And, as a result, I believe very definite information could be achieved. If the tables which Dr. Lessing has just shown with reference to the influence of added materials on the carbonization or distillation process are correct, there ought to be a very important influence of catalysts in any process of hydrogenation. That there is some interreaction between the gaseous constituents of the carbonization process and the material of the distillation process—I mean the solid material of the distillation process—and favored by high pressure is evident, I think, from some old fuel experiments at Princeton in which Hulett and Capps traced the influence of maintaining the hydrogen yielded by distillation in contact with the gases as the pressure was raised. The results showed a pronounced influence of this preliminary contact between the hydrogen and carbonizing material.

I conducted some experiments several years ago with Neville on the theoretical aspects of a process for the direct preparation of hydrogen from coke, namely, the admixture of coal with alkalis and the reaction of the same with steam at low temperature, producing not carbon monoxide and hydrogen but carbon dioxide and two molecules of hydrogen. The work showed the influence which alkalis had even on pure charcoals and also a very considerably accelerated decomposition as a result of the presence of the catalytic agent. Among other things it was shown that the carbon surface was freer from absorbed gas under such circumstances and reacted more readily with carbon dioxide. An extension of such experiments is needed.

Then in addition to the processes involving catalytic action on the solid materials, you see the various possibilities and objectives in the utilization of the water gas. The best mode of utilization is quite a difficult chemical problem to decide. On the one hand it is necessary to decide how to carry out the distillation of the coal, whether by high

temperature or low temperature distillation, proceeding thence from the coke to the water gas, and thence to the scientific products mentioned by General Patart in his paper. On the other hand one can go direct from coal to water gas with resultant loss of the by-products, the tar and tar oils, losing therefore the five per cent of products you can get that way but economizing in the fact that it would be cheaper to produce your coal water gas, the raw material for the organic syntheses. Then, too, there is the question as to what types of organic products it is best to produce. These are problems which it seems to me organic chemists must have in mind. They are problems which will change the orientation of fuel technology to a remarkable degree.

I look forward with pleasure to the developments which will be possible within the next ten or twenty years as the result of the work now started.

ERIC SINKINSON.* I should like to ask Dr. Lessing whether any work is being done to determine at what temperature the ash in the coal begins to act as a catalyst, if it does so. I did some work on American and British coals, to find out at what temperature they began to conduct electricity and at what rate the electrical conductivity increased in each sample tested as the temperature rose. Some of the coals were of low, and some of high ash content, but at any given temperature, I found no difference in the rate of conductivity for the same rate of heating.

Has any work been done to find out the precise temperature at which catalysis begins? How can the mere action of an ash be distinguished from a truly catalytic action? Then again, doesn't sulphur in coal poison the catalyst under certain conditions?

R. LESSING. Dr. Sinkinson raises a very important point, and also puts a difficult poser to me, because very little has really been done on the explanation of these most remarkable phenomena. So far we have had quite enough work to do to collect the working data to say what actually happens. I can give just one reply to his first question and that is that my work was mainly done on temperatures comparable with low temperature and high temperature, that is to say, 500°C. to 600°C. and 900°C. to 1000°C., and in both of these groups we found evidence of catalytic activity. I am not in a position to state which is the lowest temperature at which catalysts would act, although as I have indicated, even at the comparatively low temperature of Berginization I believe catalysis would take place. I see no reason why it should not do so. Moreover I anticipate that different catalysts would have different temperatures at which catalytic activity begins.

As to the question of poisoning of the catalyst with sulphur, we have to bear in mind that these catalytic conditions are not all of a positive kind. You may have a material that certainly has an indif-

*Assistant Professor, Lehigh University, Bethlehem, Pa.

ferent catalytic effect, and for that reason we cannot always attribute a promoting function to the catalysts, because whatever happens you always have a balance of product. You cannot make more total intrinsic value out of a ton of coal than is in it.

F. C. GREENE.* The speaker has approached this subject, as I see it and as my associates see it, from a laboratory standpoint. Now, in our investigations in which we ran many thousands of tons of coal for the purely selfish motive of selling the product and establishing a business, we found that we had a lot of customers who objected very much to the ash in the coal making a very bad clinker. Our work was to take our coal, our screenings, and to carbonize them at low temperatures, whereby we obtained an increased ash amount in the product. If we increased our temperatures beyond that necessary to make a true low temperature product, we obtained a clinkering ash, a very badly clinkering ash. If on the contrary we maintained our temperatures at, or slightly below, the temperature necessary to drive off the volatile contents, the resinous part of the coal, we had no clinker whatsoever. We worked with a coal that fuses at about 2150°F. and yet when our product was tried out in a great many cases practically all who tried it refused to use it in the forge fire or baker's oven. It may be that we can answer you in a practical manner in a way that maybe our theories don't explain today. At any rate, it was necessary for us to produce a non-clinkering material, and by a great many trials we finally did so, but we don't know the reason.

R. LESSING. I am very much interested in the information this gentleman is giving us, because it gives us a practical illustration of one of the tables that I showed you. I am refering to the table in which I gave you the chemical composition of the ash in coal and in coke made from it. I pointed out there that some of the material was made insoluble that had been made soluble before. Anyway we can assume that the formation of slag or potential clinker in the fine ash is dependent on the composition of the ash of the coal, not only on the amount but on the composition, and mainly, the distribution. In the beginning of my paper I directed attention to this question of distribution. When you have the characteristics of the ash, particularly the alkali and lime, in close proximity to the silica, so that on the burning off you get practically that intimate mixture or something approaching it, then obviously the higher you go with your temperature, the more easily you will flux that ash. If on the other hand you keep your temperature below the clinkering point of the ash, you are perfectly safe as regards the formation of clinker, but I should certainly like to examine a sample of the coal of which this gentleman spoke, because it leads straight to the point that the composition and particularly the distribution of the ash are of great interest. Because I take it that there would be coals containing every bit as much ash as the coal he

*Combustion Engineer, Old Ben Coal Corporation, Chicago, Ill.

spoke of and probably more, which would not behave in a similar way. I think this practical point proves that probably everybody can be right, sometimes.

F. C. GREENE. That matter is of such great importance in the transition that we have to make between low depreciated value coal and a product that will be acceptable in the market, that we are very anxious to know about it, and so will anybody be who makes a low temperature fuel from coal. Now we subjected the coal to a range of temperature, externally through the retort, of about 550°C. That would be, say, around a thousand or 1,100°F. At the time the coal had the proper temperature on it we would allow a drop of about 50°C. through the retort wall. The coal was probably at the proper temperature for making low temperature coke, namely, about 450°C. If we increased our temperature but not to the fusing point of the ash in the coal, which was about 2150°F., but probably to about 1500°F., we then got a clinker. Of course the clinker was not observable in the char material, which came out like charcoal, not like coal, but in burning it in an ordinary blacksmith forge, we would find that if the true low temperature was exceeded we would get a clinker and we always heard from the customer. These were not matters of theory with us, they were matters of practice. People wouldn't use the product that would clinker so. If some means of catalysis could be employed that would enable us to make a greater output, or a better article or would be of greater practical value, it would be of great importance I think, in the carbonizing industry.

FRIEDRICH BERGIUS.* I only wish to have a word to avoid misunderstanding. I want to say that certainly catalytic action occurs also in coal hydrogenation. Yesterday the time was too short to give every detail on this very complicated reaction, but I think I remarked at one point that there is catalytic action too, and we found out that there is a lot of things, a lot of material, which helps catalytic action. In the hydrogenation of coal we find that phenolic compounds, and alkaline compounds, give catalytic reactions, not only in regard to the percentage of coal which is transformed under the reaction, but these also influence the relation between the different products of the hydrogenation and affect the production of more or less lighter products, more or less products containing oxygen, and the transformation of phenols into hydrocarbons. All those things are more or less influenced by determined catalytic means. And perhaps it may interest you that not only solid catalytic agents are working here but also liquid catalytic materials. For instance we found an addition, of what we call tetraline, a hydrogenated naphthalene, decreased the action, which decreased the quantity of coal residue and so thoroughly showed the

*Heidelberg, Germany.

catalytic effects which we know and which will play quite an important part in developing special lines of this process in making the output better.

But obviously there is a very intense study to be made. Partly it has been done, partly it is to be done, because such catalytic agent being used in the coal liquefaction study would have to be secured against being poisoned by the gas, poisoned by the sulphur of the coal, and other material. We found that even the quality of ash plays an important role, but obviously it was impossible yesterday to give you all of this detail of the chemical work which has been done and which is being done by us, and I hope, in other places also. We will be greatly assisted in such work by scientific men.

FRANK M. GENTRY.* The industrial transformaton of bituminous coal into organic technical products is one of the most interesting and important fields of applied chemistry today and we should feel honored at having been addressed by so distinguished an authority as General Patart.

In the early part of his paper, General Patart has defined low temperature carbonization as the coking of coal under conditions such that no part of the charry mass is subjected to a higher temperature than 600° C. The matter of thermal definition of low temperature carbonization is in considerable disagreement among the authorities. Parr and Layng in one case have defined it as below 750° C. to 800° C., while Bone considers it not beyond 550° C. to 600° C., and Glund fixed the range as between 500° C. and 600° C. I know of some particular experiments where it has been taken to include as low a temperature as 300° C.

This disagreement may be understood when it is recalled that the experimenters used coals of widely different behavior under carbonization and that some were studying low temperature carbonization with particular regard to smokeless fuel while others were considering mainly the liquid and gaseous products. To my mind, low temperature carbonization is the distillation of coal at or below the cracking temperature of the hydrocarbons in primary tar. This avoids a specific temperature, for temperature of reaction is, of course, a function of the physical conditions of retorting. Primary products, which are characteristic only of low temperature processes, may be obtained in some cases as low as 450° C. and in some cases as high as 1000° C., depending on the physical circumstances, the coal, etc.

General Patart has dealt almost exclusively in his paper on the transformations that take place between carbon monoxide and hydrogen under pressure in the presence of suitable catalysts. It was shown that the chief products were methyl alcohol, its homologues and oxygenated compounds. It might be interesting to point out that carbon

*Assistant to the Consulting Engineer, The New York Edison Co. (Submitted in writing after close of meeting.)

monoxide and hydrogen in the presence of suitable catalysts unite under ordinary pressures to form an entirely different series of products. Aliphatics, principally methane and higher hydrocarbons are yielded. This has been demonstrated by the experiments of Sabatier who used nickel as a catalyst at 250° C., by Cedford and by Medsforth who experimented with oxides of the rare earths. Dreyfus is said to have effected the transformation into methyl alcohol at low pressures by the use of special catalysts, but the process was abandoned.

Another interesting phase of the subject not touched upon by General Patart is the effect of electric discharge upon the reaction between carbon monoxide and hydrogen. Various experimenters have procured formaldehyde, carbohydrates, and hydrocarbons as their reaction products. Of chief interest among these is the research of Hulgren in a high tension arc at ordinary pressures. The temperatures attained ranged between 2000°C. and 4000°C. Eighty per cent. of the gaseous mixture condensed to volatile oils and heavy hydrocarbons. When carbon dioxide was used instead of the monoxide, the efficiency of condensation was reduced to fifty per cent. The residual gas was recirculated.

Regarding the proposal to utilize the cleansing gas from the methanol process for the distillation of coal under pressure, this does not seem in general a sound proposition from the standpoint of practical economics, for it involves high pressure coking chambers and other expensive construction to dispose of a waste product. As long as the coal must be heated to 400° C. under a gaseous pressure of 200 atmospheres, it seems more logical to crush the coal, substitute hydrogen for the cleansing gas and liquify the coal directly by berginization without proceeding indirectly to the same end.

NATIONAL SUPPLIES OF POWER

By John Hays Hammond and F. G. Tryon

This international conference is, we believe, to be regarded as one of transcendent importance, not only in its economic aspect but in the evidence it gives of the spirit of cooperation among the great scientists of the world to carry on researches of inestimable value to industry and to mankind.

"By mutual confidence and mutual aid
Great deeds are done and discoveries made."

Science recognizes no political boundaries. No tariff walls or embargo can prevent the interchange of results of scientific investigations. We feel sure that in this the great men of science will emulate the spirit which has characterized the medical profession in its aim by interchange of results of experience to eradicate disease.

President Baker and his associates are entitled to the highest praise for their remarkable achievement in bringing about this conference and the distinguished visitors have earned the gratitude of the American people for their contribution to its success.

Our Increasing Dependence on Power

The outstanding characteristic of modern life is its enormous use of power. The economic rank of a nation may be gauged by its installed horse-power per inhabitant. In a highly industrial country the per capita consumption of energy—coal, oil, natural gas, and water-power—may be 90 times as great as it is in British India.

In the manufacturing industries of the United States, each worker is backed by an average of 3 horse-power, of which two-thirds is electrified. Chiefly because of increasing use of power, the output per worker is growing larger and larger. It is not merely by comparison with the age before machinery that an increase is shown. In the classic example of pin making, the output per worker today is indeed 3,000 times what it was when Adam Smith wrote the Wealth of Nations, but some of the most remarkable progress is going on under our noses. The census returns show that from

1919 to 1923 the volume of manufactured goods increased 19% while the number of employees actually decreased. In the manufacture of pig iron the product per worker has increased 7-fold since 1900; in the automobile industry it has trebled in a dozen years. The widely quoted statement of two American engineers that each man, woman and child has the equivalent of 30 servants was true when it was made, but at the rate we have been buying

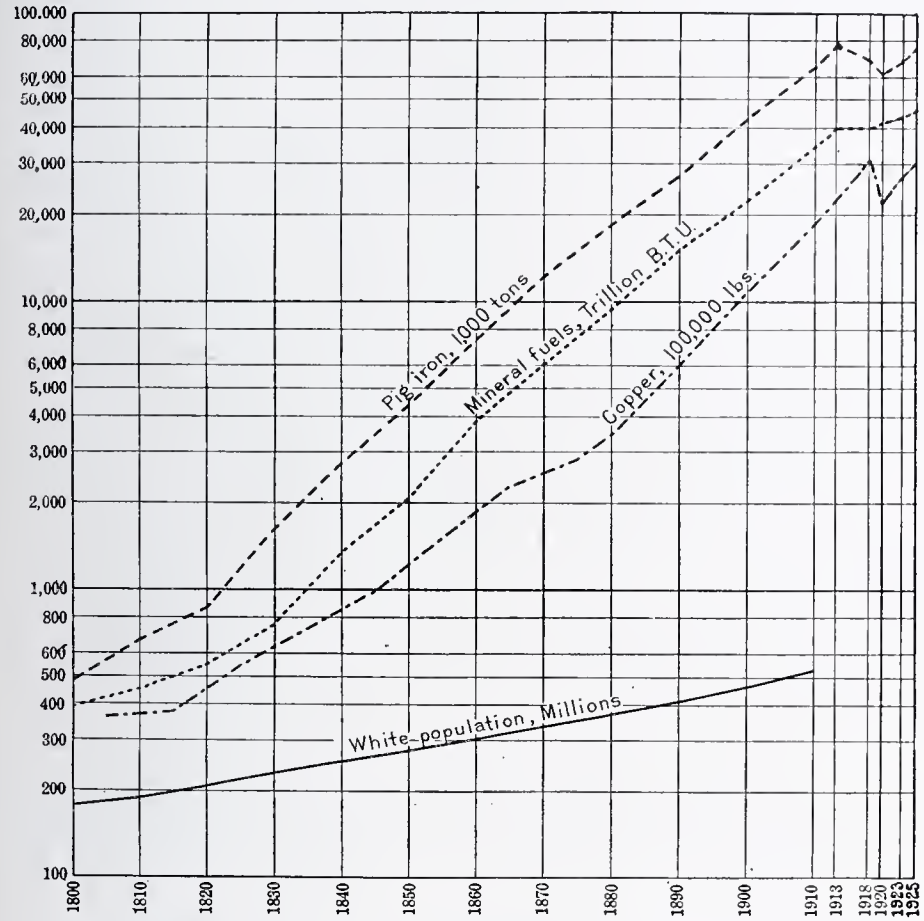

FIG. 1. RELATIVE RATE OF GROWTH OF MINERAL PRODUCTION AND OF THE WHITE POPULATION OF THE WORLD

While the white population of the world increased about 3-fold from 1815 to 1914, the production of the mineral fuels (coal, oil and natural gas reduced to their heat values in British thermal units) increased 75-fold. The principal metals showed a corresponding increase. The data are plotted on ratio paper in which a straight sloping line indicates an increase by a constant percentage each year, like compound interest. It will be seen that up to the world war, the consumption of the mineral fuels was increasing at the rate of about 5.5% a year. Note the sudden check of the rate of growth after 1913.

autos since, the figure today would be nearer 50 servants. In fact the power of our automobiles, now at least 500,000,000 horsepower, is seven times as great as the horsepower of all the steam railroads of the country. Two pounds of coal will develop as much energy as a man at heavy labor for a day, and as Dr. T. T. Read has shown, at the rate the American miner digs coal, 10,000 men in the bituminous mines produce as much energy as could be developed by the 41,000,000 wage earners in the United States. So common is the use of power that we have ceased to remark on it. In the cities the electric light is all but universal, and the farmer in his flivver drives 8 times the power of the Roman gentleman in his chariot.

Not only are we utterly dependent on power, but we require it in ever-increasing amounts. In the hundred years from Waterloo to the Marne the white population of the world increased 3-fold while the use of coal and oil increased 75-fold. (Fig. 2) Year by year, and with astonishing regularity, the consumption of the fuels went on increasing like a sum at interest, compounded at 6% a year. The growth was retarded by the war, but it is now increasing again, and although in recent years there has been a tendency to over-production in bituminous coal, it is clear that in general our energy industries—coal and oil, gas and electricity—must prepare for continuing increase in demand. It is not enough to maintain the present rate of supply. Our material civilization is an Oliver Twist, asking for more and still more energy, and the possibility of raising the standard of life turns perhaps more than on any one thing on making power more cheap and more abundant.

The Power Resources

This insatiable growth of demand has caused many thoughtful men to ask what will happen when the oil and coal are gone. Some day mankind must learn to balance its energy budget and extract each year from the renewable sources of energy—the sunlight, wind and water—an income of power equal to its expenditure. It is a blind optimism that assumes this can be done by some magic formula of "wringing power from the air," for the correct attitude is neither heedlessness nor despair, but resolute determination to find the way out. Especially common is the notion that all we have to do is to harness the water powers of the country. The great Steinmetz, who had done so much to make the long-distance transmis-

sion of hydro-power possible, remarked before his death that if every drop of rain falling on America could be harnessed, it would still not carry the load already borne by coal. The potential water power that can be developed without extremely expensive storage is placed at 55,000,000 horsepower available 50% of the time. Of this 10,000,000 has already been developed and much of the undeveloped is in sections of the country remote from industrial requirements. As a matter of fact, water power furnishes only 4 or 5% of the total supply of energy used by the people of the United States. The other sources of supply are shown in Fig. 2.

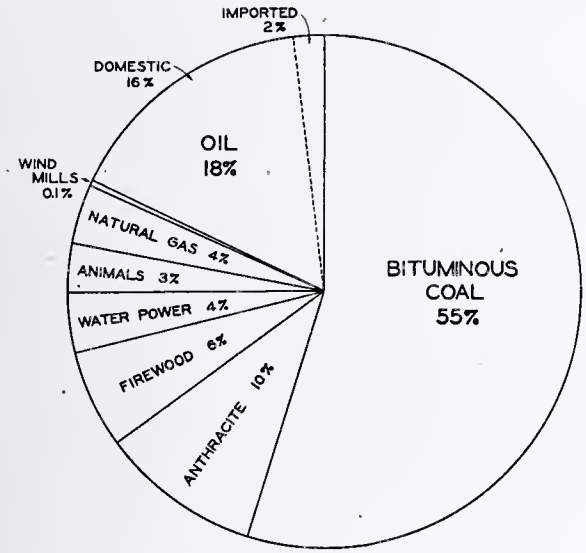

FIG. 2. SOURCES OF THE ENERGY SUPPLY OF THE UNITED STATES, 1923.

The total heating value of the fuel consumed or of the fuel equivalent of other sources of power was 26,780 trillion British thermal units. In this computation water power, windmills, and work animals are represented by the heat units in the fuel which would be required to perform the same work.

Note that 87% of the total energy is supplied by the mineral fuels and that in spite of the recent rapid growth of petroleum, two-thirds of the total is supplied by coal.

The mineral fuels are overwhelmingly our dominant source of power, and in spite of the rapid growth of petroleum, two-thirds of our energy is derived from coal. While improved methods of efficiency in the utilization of oil and its products of distillation and more efficient methods of extraction of oil from the ground, together with the certainty of future discoveries of new supplies of oil in regions not yet tested, will prolong the lift of the proven re-

serves, the supply of oil is nevertheless exceedingly limited compared with that of available coal. Vegetable matter can not take over the load because we need the plants for raw materials and food. Barring some revolutionary discovery of science like the release of atomic energy, concerning which Prof. Ernest Rutherford has uttered a note of caution, the future of America is tied to bituminous coal.

Increasing Natural Difficulties in Mining

But to the man on the street even this absolute dependence on coal is not alarming, when he is told that at the present rate of consumption the reserves would last 4,000 years, and the day of exhaustion seems to him as distant as the dream of atomic energy. What the man on the street does not realize is that however remote the day of absolute exhaustion may be, we have an immediate problem in the increasing natural difficulties of mining and the tendency toward increasing cost. He does not know the never-ending battle which goes on underground between the increasing handicaps of nature on the one hand and the engineer and scientist on the other. In industries that do not rest upon exhaustible resources the natural conditions are constant, but in mining, as the richer mineral is removed and the workings grow deeper, the natural conditions grow harder, and there is thus a constant tendency toward higher cost which nothing but better methods can absorb. It is only the technical men who can prevent the increasing difficulties of nature from being passed on to the consumer in the form of a higher price. Fortunately, as we shall see in a moment, the technical men have been very resourceful.

That the tendency toward increasing natural difficulties is very real is easily shown by examples. If the world still had to get its tin from the old mines of Cornwall, rich as they once were, the price would be prohibitive indeed! Here the situation has been saved by the discovery of new deposits in other parts of the world. In the British coal mines the annual output per worker has been declining since the 80's in spite of many technical improvements, primarily because of the increasing natural difficulties. American oil companies are having to search harder and drill deeper and deeper to maintain production and already are beginning secondary recoveries, which are inherently more costly than flowing wells.

Our own bituminous coal mines are still easy to work, but eminent authorities warn here, too, of a day of increasing cost, as when Dr. Ashley shows that a generation will see the end of the Pittsburgh bed around its native city. In our anthracite mines, the natural conditions are getting steadily harder. The average depth has increased 77% the last generation and the average thickness of the beds is barely half what it once was. Fig. 3 shows what has been happening in one of the anthracite districts and the story it tells is heard in older mining communities all round the world.

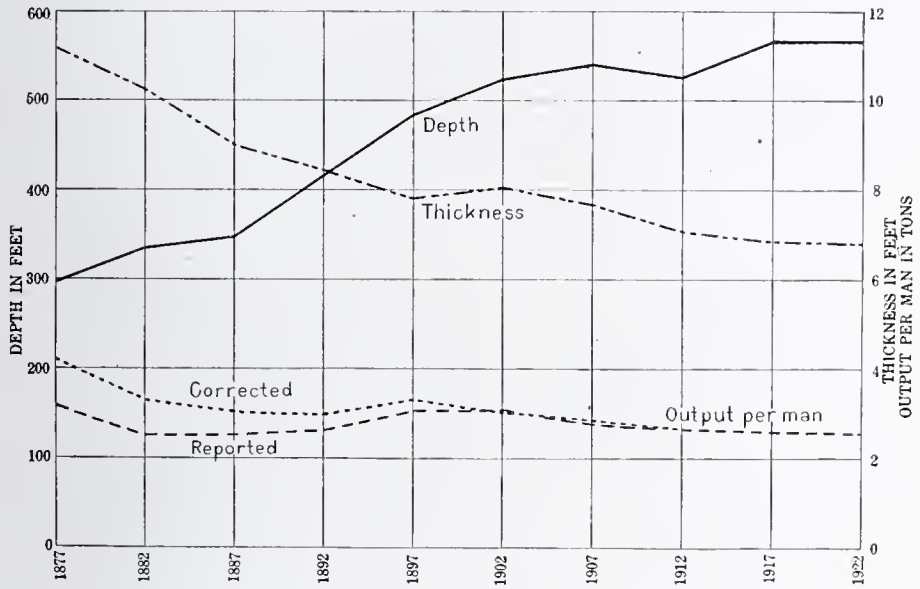

Fig. 3. Increasing Natural Difficulties in Mining, as Illustrated by the Nanticoke Anthracite District.

In mining, as the richer mineral is exhausted and the workings become deeper, the natural difficulties increase. The tendency is well illustrated by the anthracite region of Pennsylvania. In the Nanticoke district, the average thickness of seam worked has declined from 11.19 to 5.83 feet in 45 years, and the average depth of workings has increased from 296 to 567 feet. The output per employee underground, per day, has therefore tended to decline. In 1922 it was 2.58 gross tons. In 1877 it was 3.15 tons, a figure which should be corrected to 4.20 tons to make it comparable with that of 1922. The correction is necessary because of the change in the length of the working day and the practice of recovering the small sizes of coal which have since occurred. (Data from D. C. Ashmead).

This tendency for natural difficulties to increase is common to all mining operations. To offset it constant improvements in methods are necessary, if we wish to avoid an increase in the price to the consumer.

Research to Offset the Growing Natural Difficulties

Between us and this constant pressure of rising natural difficulties stand only the scientists and engineers, as the legions stood between Rome and the rising tide of the barbarians. Except as they can find ways to outwit nature by better methods either in mining or refining or in converting the fuel into power the world faces rising prices of energy.

Fortunately for us consumers, science and technology have so far been winning over the difficulties of nature, and in this hall it is fitting to recall some of their achievements:

They have increased the output per worker in American bituminous mines 67% since 1890.

They have reduced the fatal accident rate in the British coal mines to one-fourth of what it was in 1850.

By secondary recoveries they are promising to double and treble the recovery of oil from the sands.

In 10 years they have doubled the percentage of gasoline recovered from the crude.

In the gold mines of the Rand in South Africa mining operations are being conducted today at depths of several thousand feet at a cost considerably less than prevailed in working the upper areas 30 years ago.

Perhaps the best single measure of what science and engineering have done for us in the field of power is the improvement in the thermal efficiency of the steam engine (Fig. 4)—best because the record runs back long enough to show the accumulated contributions of many inventors. Without going back to the days before James Watt, when Newcomen's engine consumed 30 pounds of coal per horsepower hour, we may pick up the tale with the steamship Savannah, the first steam vessel to cross the Atlantic. The Savannah burned 10 pounds per horsepower hour. That was in 1820. By 1907, the unit consumption had been cut to 1.4 pounds on the Lusitania, an increase in fuel efficiency of 700%. Remarkable as this showing is, it is eclipsed by what the electric utilities have been doing since the war. The consumption of coal per kilowatt hour has been reduced from 3.2 pounds in 1919 to 2.1 pounds in 1925, an increase in efficiency of 54%.

Remembering that the improvements from the Savannah to the Lusitania were spread out over a period of 86 years and that those

cited for the electric utilities were concentrated into the space of 6 years, it will be seen that general progress in fuel efficiency has probably never been faster than it is at the present day; and what has been cited for the utilities could be cited in somewhat lesser degree for the railroads, the metallurgical industries, and other consumers. What these economies mean to the consumer is illustrated by the fact that in spite of the rise in commodity prices and wages, the retail price of electricity for household use is less today than it was in 1913. Even rates for large-scale users of power, though greater than in 1913, have increased by a smaller ratio than the general price level.

This achievement of the electric central station industry may be taken as a type—a specially successful type—of the service that the legions of science and engineering render in fighting the increasing difficulties of mining.

Because of our utter dependence on cheap energy, you and I as consumers ought to give them every facility for pursuing their research.

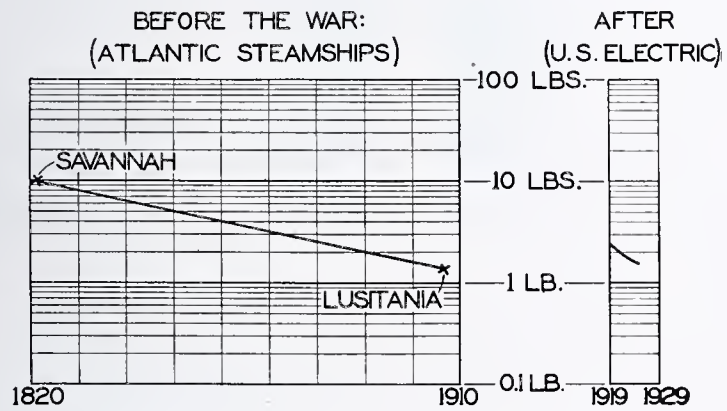

FIG. 4. PROGRESS IN THE FUEL EFFICIENCY OF THE STEAM ENGINE AS INDICATED BY THE COAL CONSUMED PER HORSEPOWER HOUR

The increasing efficiency of the steam engine illustrates the work of science and engineering in offsetting the rising natural difficulties of mining. The diagram is plotted on ratio paper and the steeper downward slope of the consumption line for the electric utilities from 1919 to 1925 indicates that the progress in fuel economy since the war has been much more rapid than before. This remarkable decrease in unit consumption is one of the causes of the depression in the bituminous coal industry.

For except as the technical men find new methods and further improvements in mining, in refining, in business organization, in utilization, the pressure of mounting natural difficulties will cause rising costs of energy and chill our material well-being.

A COMMON PROBLEM OF THE POWER INDUSTRIES

Interdependence of the Energy Producers

Now here the point must be driven home that these problems of research are of vital importance not simply to the coal industry, or the oil industry, but to the whole group of energy industries—to natural gas, to manufactured gas, to by-product coking, to electric power—and we might add to the railroads, which with their coal cars and tank cars are still incomparably the greatest transporters of energy, and to the automotive industries whose future is tied to liquid fuel. All of these industries, if we stop to think of it, are clearly parts of a common service, the service of heat and power. Step by step, the developments of business and technology are throwing them more closely together and the particular technical advances which we are met here to discuss promise new and startling crossties between them.

We must get away from the natural but somewhat provincial habit of thinking of the coal industry as if it had no relation to the oil industry, or the gas industry, or the electric industry. We must begin to think of the power supply as a whole, matching up the total supply of energy on the one hand against the total requirements on the other.

World Competition of the Sources of Power

For an example of how the energy industries react on each other we have only to turn to the world relations of oil, coal and water power since 1913.

The condition of excess capacity, idle mines and idle miners, over-production and cut-throat competition which has characterized the bituminous market in the United States in the last few years, exists to a greater or less degree all around the world. The Canadian mines are over-developed, and the recent events in Europe have revealed competitive forces the effect of which has not yet been fully sensed. For in the world as a whole the growth of

coal demand which was so characteristic before the war has seemingly stopped. If we take the total tonnage of lignite and bituminous and anthracite coal, we find only one or two years since the war in which it equalled the tonnage of 1913, and this comparison ignores the fact that the output of lignite has largely increased, while the output of bituminous and anthracite coals is actually

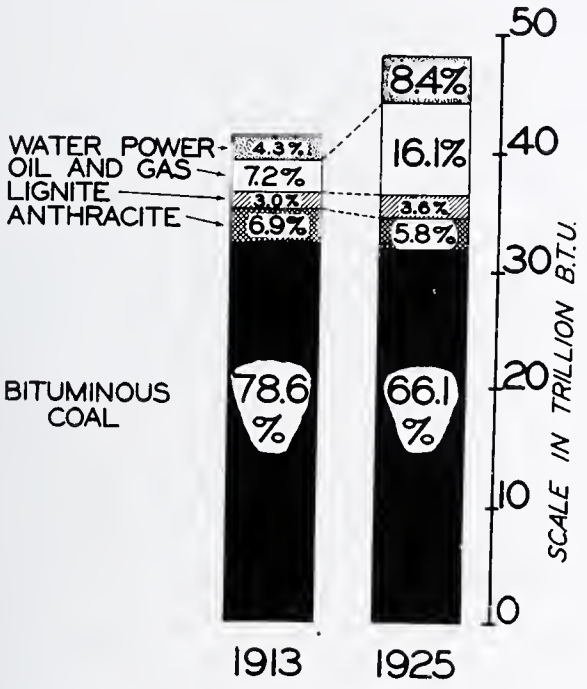

FIG 5. WORLD CONSUMPTION OF COAL, OIL AND WATERPOWER, 1913 AND 1925.

Counting all sources, the world's consumption of energy materials in 1925 was 71% greater than in 1913. The increase came exclusively from oil and gas and water power. The increased use of water power was equivalent to 80 million tons of coal a year and the increased use of oil and gas to 170 million tons of coal.

There was an increase in the consumption of lignite, but an actual decrease in the total of anthracite and bituminous coal. As a result of these changes, bituminous coal furnished only 66.1% of the total energy in 1925 as against 78.6% in 1913.

(Because of the strike of the American anthracite miners in 1925, and the substitution of bituminous coal, the figure for anthracite used in the diagram represents the production of 1924, and the figure for bituminous coal has been adjusted accordingly, by deducting the quantity used to replace anthracite.)

less. Taking account of the fact that lignite is inferior in heating value, and reducing the tonnage figures to equivalent thermal units, we find that the world's output of coal in 1925 was slightly less than in 1913 (Fig. 5).

But, in the meantime, the total supply of energy in the world has increased. Including water power, oil and gas, it was 17% greater in 1925 than in 1913. The increase has come entirely from coal's competitors. The production of water power has doubled since 1913 and the production of oil and gas much more than doubled. The world increase in water power developed over the pre-war figures is now equivalent to 80,000,000 tons of coal. The increase in oil and gas is equivalent to 170,000,000 tons of coal.

It means very little to say that the world output of coal is no less than it was before the war. This statement overlooks the fact that the coal industry all around the world was adjusted to a steadily increasing demand. The world demand grew before 1913 at the rate of about 38,000,000 tons a year. In England it was increasing slowly, but nevertheless increasing. It increased at a faster rate in France, much faster in Germany, faster still in the bituminous mines of Canada and the United States, and very much faster in those outlying countries of Australia, South Africa, India and Japan, which were relatively new entrants in the field of coal production. This means that every year new miners had to be recruited and new mines opened, not merely to replace abandoned ones but to take care of the expected increase. Miners' sons could look forward to finding employment in the mines. Business might be slack for a while, but the growth trend of demand always helped to take up the slack. The point is that the whole industry, from miner to operator to exporter and distributor was geared up to expect, and to expect confidently, a steady growth in demand. To such an industry the fact of stoppage of growth may be quite as serious as is an actual decline of output to stationary industries.

These broad facts of supply and demand are the underlying cause of the world-wide depression which has been apparent in the coal industry. Increasing fuel efficiency, such as is shown by Fig. 3, successful competition of water power and petroleum, coupled with an absolute decline in the use of energy in some of the war-stricken countries, have brought about a nearly universal tendency of over-

production in coal. The tendency is not the only factor, of course, but it is the dominant one.

The direct competition of oil and coal as boiler fuel has been unfortunate. Granted an over-production of crude oil, it was inevitable that the oil industry should sell it in competition with coal at whatever price was necessary to move it. But this meant the sacrifice at low prices of a substance potentially worth much more, and a consequent loss of potential income to the oil industry. To the coal industry it caused great difficulties, and from the national viewpoint it should be the effort of industry to conserve oil supply as far as possible and to discourage its use where coal is available in order that its inherent value should not be sacrificed to market consideration—the by-products of oil being too valuable to justify its use as boiler fuel.

This competition of oil and coal is mentioned as an example of the way the energy industries react upon each other. The future of one is dependent on developments in the others, and no one responsible for directing investment in one can afford to overlook the others.

New Inventions and the Energy Market

But the competition of oil and coal, distressing as it may have been, is not nearly as significant to the fuel industries in the long run as the widening and diversifying of the energy market that is going on. The economic and technical changes now in progress are making the different forms of energy more flexible and more easily inter-changeable and the energy industries are growing more dependent on each other.

Results of electric transmission.—Consider first electricity as a means of transmitting power. Everyone knows how it is making possible the use of remote sources of power, not otherwise accessible. More important, it is making possible the transformation of crude stuff of energy-fuel of all kinds or water into energy of exactly the kind the consumer wants, whether mechanical motion, light or (within limits as to amount) heat.

Once upon a time a good light could be made only from certain rare long-flame fuels, such as sperm oil or kerosene. Now a much better light can be made out of any fuel, even out of anthracite culm, which burns with almost no flame, and which our ancestors

considered would not burn at all. Or the same light can be made from falling water without any flame at all. It is not too much to say that with the general introduction of electricity all the raw sources of energy—the several fuels and hydro-power—have come into a competitive equilibrium which any change in relative cost tends to disturb and in which each one is at least a potential bidder for any part of the energy market.

If this is so, it becomes a matter of the greatest consequence in planning investment in any one of these industries to forecast what is likely to go on in the others.

Selling energy instead of raw fuel.—In the second place, consider the changes in the relations of the energy industries to the ultimate consumer. A generation ago, the method was to quarry out chunks of coal and deliver them to the consumer, leaving him to make his own heat or generate his own power on the spot. But the consumer is not interested in chunks as such; what he really wants is the energy in the coal, and we are beginning to sell him not raw fuel, but heat, or light, or motive power.

It may seem a far cry to the day when the consumer will never see the raw fuel, and yet in retrospect it is astonishing how far we have already traveled in this direction. Forty million tons of coal now reach the consumer as electricity, and eighty-five million tons as gas or coke, and the percentage increases every year. The tendency will be greatly stimulated by the revolution in house heating which has begun. The invasion of the oil heater has taught the housekeepers of America that it is possible to dispense with smoke and shovels and ashes, and they are not going back to raw coal simply because of a rise in the price of oil.

The next step will be the development of means to burn the cheaper fuel, coal, in ways that will yield the superior service of oil at less expense. Whether it will be powdered coal or semi-coke, or anthracite fines, or simply fine bituminous coal is for the engineers to work out, but there seems no reasonable doubt that means will be developed to burn coal in household furnaces with automatic stoker and draft controlled by thermostat, and with automatic removal of ash to a pit outside the cellar that will give the advantages of oil at lower cost. Whatever the means, our descendants will look back with tolerant amusement at our present systems of burn-

ing raw bituminous coal in household furnaces much as we look back to the whale oil lamp and the tallow dip.

Interchangeability of the sources of energy.—And in the third place, the different sources of energy are becoming more and more interchangeable. The ingenuity of the technical men in converting fuel into any form of energy desired makes the form of the raw fuel count for less and less. There was a day when only sizeable lumps of coal could be used. The miner loaded the lumps out with a fork, not with a shovel, and the fines were left underground as worthless. Gradually the fine coal came into its own. The automatic stoker gave it a positive superiority over lump coal for the production of power. The automatic stoker on the locomotive has opened the railroad fuel market to small coal, and history would fail to repeat itself if the automatic stoker did not in time supplant the hand firing of lumps in the boiler rooms of ships as well. The time may come when the beautiful lumps of Welsh Admiralty coal will be a museum relic, less venerated perhaps but no less obsolete than Nelson's flagship, the Victory.

The use of the fines enters still another phase in pulverized coal, which, aside from the ash it contains, may be used as if it were a liquid or a gas.

And while one set of fuel engineers have thus been transforming the shape of coal, another set have been transforming its chemical composition. They have shown us how to make artificial anthracite out of bituminous coal and steam coal out of lignite. They have shown us how to make gas out of coal, or out of oil, or even out of any combustible. And now to make the change complete our guests at this conference are showing us how to make coal into oil.

Converting Coal into Oil

A great forward step.—As to this last great step, the conversion of coal into something like gasoline, it is dangerous for mere laymen to pass on these brilliant advances in applied chemistry. The authors of this paper have made no study of the new processes and have no verdict to pass on their commercial value. But if only part of the work presented at this conference bears practical fruit, it does not seem too much to hope that the problem of providing a substitute for petroleum when higher prices show the need is in a

fair way to be solved. At least it may be said that the new developments are sufficiently promising so that all the energy industries ought to stop and inquire what changes in plan they make necessary.

Coking at either high or low temperatures, as we know from ample experience, gives a very good gasoline substitute as one of the by-products, but this method of coal treatment has never promised to take over the burdens now carried by petroleum because the yields of gasoline substitute per ton of coal treated are small, say 2 to 5 gallons a ton. If the entire production of bituminous coal were coked, and the benzol recovered, it would supply barely a seventh of the country's present consumption of gasoline. But the new methods discussed at this conference, which turn on the hydrogenation or complete gasification of the coal, promise yields per ton equivalent to from 40 gallons of gasoline up to as high as 200 gallons of gasoline.

As to the question of cost and price—the first one that rises in the mind of the practical investor—there is no evidence that these new methods can compete with gasoline at 21 cents a gallon; but there seems reason to hope that after the necessary period of experiment and development they can compete at the price levels which prevail today in Europe, and that if and when a shortage of gasoline in this country forces any enormous increase in price, we may look to coal for a measure of relief. The new processes do not, therefore, appear to threaten dangerous competition to the petroleum industry, but rather to offer it supplementary sources of crude whenever high prices indicate that supplies of well oil are no longer adequate to the world's needs.

To the layman, therefore, the new developments seem an unmixed boon.

Much remains to be done.—In this moment of enthusiasm over new achievements of science it is ungracious to utter a word of caution. What the new processes seem to offer is another secondary reserve beyond the oil sands, resembling in many ways the secondary reserve of oil shale. Whether the coal processes will be more or less expensive than oil shale processes we can not yet be certain. There is some danger that in our satisfaction we may relax our efforts to increase the efficiency of utilization of our oil sands themselves. After all, oil from flowing wells is the cheapest and most convenient

form of energy for many purposes yet given to man, and it will be an undeniable handicap when we have to forego it for material from secondary reserves, inherently of higher cost. The urgent need remains of pushing every line of research and practicing every economy that promises to prolong the life of our present oil fields. Let us be encouraged by these discoveries to redouble the efforts to husband our resources. The lesson of the new discoveries is not less but more endeavor.

Readjustments by the Power Industries.—And now, just consider for a moment how this latest technical advance, wherever higher prices call it into use, will tend to draw the energy industries still nearer together, and how each one of them must plan its future in the light of new possibilities. To the coal industry it opens a new market, which may ultimately prove very large.

To the oil industry it opens supplementary supplies of crude materials to utilize its enormous investment in refineries and distribution systems. It is at least conceivable that the future will regard it just as important to a refinery to be located near supplies of coal as to be near supplies of crude oil.

To the manufactured gas industry it suggests a most promising field. All the new processes make large use of hydrogen, and derive their hydrogen from water gas. The gas industry already has the knowledge and the equipment to make water gas on a large scale. One of the obstacles to the use of gas for heating houses has been that the winter load would require an enormous plant capacity which would be idle in summer. Can the gas industry, as Dr. Fieldner has suggested, get into the house heating field in winter, and in summer use its surplus water gas capacity to make oils?

To the electric power industry the new developments suggest a great new line of products. Central stations are already experimenting with the recovery of by-products from their coal. They seem destined to handle a greatly increasing proportion of the output of coal. It is conceivable that great amounts of oil may be derived as an incident to the production of power.

Thus it seems not at all unlikely that future supplies of oil products will be a joint contribution from all of the great energy industries. The relationships will be sometimes competitive, sometimes cooperative, but in either event they will become ever closer. It would be surprising if they did not lead to financial inter-relation,

just as the electric and gas industries are already financially affiliated.

To forecast just what these relations will be is far beyond the writers of this paper, but enough perhaps has been said to show that the study of these developments both in their technical and their economic aspects is a task not simply for the coal industry acting alone, nor for the oil industry acting alone, but that it is important to coal, and oil, and natural gas, and manufactured gas, and electric power—all together. The problems of power now concern all those engaged in any part of the process of produucing and distributing power. The power industries are growing economically interdependent.

INDISPENSABLE RESEARCH

Fundamental Sciences.—Every encouragement should be given to the necessary research, and here it is important to stress that fundamental research in the underlying sciences upon which applied science and engineering rest. We are, perhaps, less likely to forget the necessity of pushing invention and practical work, than the indispensable research which is the theoretical basis for that work. We must see that the fires of science in our universities are kept burning brightly. We must build up the engineering institutions of which our host tonight is a happy example. We must give ungrudging support to our public agencies, such as the United States Geological Survey and the Bureau of Mines, on whose work the whole structure largely depends.

Scientific research to extend the use of soft coal is of incalculable value to the bituminous industry, and it is but reasonable to expect that the mining and power industries will show their appreciation by creating a fund to assist not only American but also European experts in carrying on their investigations. It would be money wisely expended.

America ought to double and treble her investment in research. Here is an item in the budget where to be penny wise is pound foolish.

Economic Research.—One word more. The research problems are not all technical. Economic problems also demand investigation. The growing inter-relationships of the power industries require intensive study of these inter-industry fringes of competition and

cooperation. We need studies of the demand for energy in all its ramifications, an itemizing of supply and requirements, an examination of marketing and distribution. These things are basic. The scientist needs them in determining which points to attack first. Above all, the executive and investor need them.

Imagine yourself an investor in public utilities considering the erection of a pile of steel and concrete with a life of 50 years. Aside from the question of condensing water, will you place it near coal or near the anticipated load? The correct answer will turn largely on whether you expect to recover by-products and what outlets you require to absorb them. On all these economic problems we need continuing study, some of it under public auspices, so that all the branches of the energy industries may have access to the basic facts.

The Hope of the Future

Thus far nothing of the man-on-the-street—the ultimate consumer. We assume you will agree he ought to be the residuary legatee of the technical advances, the recipient of what net saving can be made in cost and service. Can he see the legions of science and engineering which stand between him and the gradual exhaustion of the fuel resources, the rising tide of natural difficulties? If he does, he will leave nothing undone to foster the work of science. Because, if we can keep power abundant and cheap, we may hope to abolish poverty and win the "good life" for all.

WHAT BITUMINOUS COAL IS DOING FOR ITSELF AND FOR THE NATION

By WALTER BARNUM
President, National Coal Association

On behalf of bituminous coal operators as represented by their nation-wide organization, the National Coal Association, I express appreciation of the interesting program and the able group of speakers provided for this conference by our host, the Carnegie Institute of Technology. Great good must come for both producers and consumers of bituminous coal from the results of the deliberations of this gathering.

Speaking for the bituminous operators of this nation, I can vouch for their lively interest in all research work pertaining to new utilization of coal. Owing to the great potential capacity of the bituminous mines of the United States, our mine owners will welcome any method of increasing consumption or adding value to their product. When, for instance, the production of motor fuel by gasification and liquefaction of coal has been established on a commercial basis, the bituminous coal operator will have the pleasant experience of a heavy demand from a new customer. It is not amiss to note at this point that the Research Committee of the National Coal Association recently has been in touch with the principal fuel specialists of Europe, as well as of this country, with a view to presenting a world-wide summary of activities with respect to coal research. We hope this summary, which will be supplemented from time to time as important research activities are completed, will have the effect of bringing about a practical coordination of the numerous activities in this country, at least. It is my observation that nearly every scientist and engineer engaged in research work necessarily has his eyes glued to the problem before him; he doesn't have opportunity to see the entire picture. Our Association proposes to paint that picture with the thought that it will not only do away with unnecessary duplication, but also that it will prove a helpful guide and inspiration to the actual research worker, to the man who is producing coal and to the general public.

Research is of great importance to the general public as well as to those directly concerned in the mining of coal, and that is equally true whether reference is made to coal for domestic purposes or as industrial fuel. Our modern industrial organization, our mining, our manufacturing, and our transportation alike are now and will continue to be dependent upon a constant supply of bituminous coal. Improvement in methods of combustion which bring about a more complete utilization of the heat values contained in that fuel will benefit the consumers of all commodities.

For the greater part of the work of the world there is no substitute for bituminous coal. Considerable attention is being attracted at the present time to the extent to which petroleum and its products on the one hand, and hydro-generated electricity on the other, have been displacing coal as a fuel. In view of the increase in the use of these sources of power during the last few years, it has been easy to acquire an exaggerated idea of their relative importance.

So far as the use of petroleum and its products for general industrial purposes is concerned, two facts are conclusive evidence of the shortness of the time during which much dependence can be put upon this source of power. First, we have the recent statement of the Federal Oil Conservation Board calling attention to the rapidly approaching exhaustion of the known resources of petroleum in our country. Discoveries of new fields and a higher percentage of recovery will add to the supply, but the inevitable advance in price will check consumption. With all allowances for these considerations, it is evident that the time is very near at hand when this fuel will no longer be a possible substitute for bituminous coal.

The second fact referred to is the growing demand for the lighter products of the distillation of petroleum for use in internal combustion engines, and especially in automotive vehicles. The consumption of gasoline in this country increased from about 3,000,000,000 gallons in 1918 to nearly 9,500,000,000 in 1925. This demand is so insistent that it will continue, even in the face of an advancing price, which eventually will remove petroleum from heating and steam fuel use.

At the present time a rapid development of our water power resources is taking place. Some people may be so impressed by the number of hydro-electric installations now being planned or constructed as to forget how limited is the opportunity for future developments of the same nature. A report of the United States Geological Survey in 1924

estimates the theoretically usable capacity of all water power resources in the United States as 72,000,000 H. P. Of this total approximately 9,000,000 H. P. have already been developed. Therefore, the power theoretically remaining and available amounts to about 63,000,000 H. P.

This figure sounds rather imposing and suggests the possibility of a great expansion in the use of this source of power, but that expectation will be considerably modified by a study of its geographical distribution. There is located east of the Mississippi River and north of the Ohio and Potomac Rivers only about one-sixth of our total undeveloped water power, representing a possible development of 11,880,000 H. P. of hydro-electric energy. But the development of water power sites has gone further in this section of the country than in any other. In this area nearly one-third of the theoretical capacity has already been developed, while in New England the development has reached 54% of the possibilities. How relatively unimportant this remaining undeveloped water power is to the section of the country under discussion can be appreciated when it is understood that that territory already consumes annually more than ten times as much bituminous coal as would be required to generate this additional power by steam. Further, it is a fact well known that because of the increasing efficiency of steam generation probably none but the most economical remaining water power sites will be developed.

These few statistics will emphasize the fact that bituminous coal has been and must continue to be our chief reliance for the development of the enormous amount of power necessary to maintain our modern industrial life. For that reason any inventions or improvements in technique which will increase the energy-producing capacity of bituminous coal are matters of great significance.

Since there is no other fuel available in quantity, consideration may well be given to the way in which the bituminous coal mining industry has met its responsibility. Fortunately we have the record of the industry for the past half century from which to demonstrate its efficiency in fueling the nation. Ability to render service in the future may be judged from past performance.

During the five decades from 1870 to 1920 the United States passed from a primarily agricultural to an industrial nation. As measures of the increased importance of industry, the growth of transportation and manufacturing are the most significant factors. In 1870 the railroad mileage of the country amounted to 52,922 miles; in 1923 that

mileage had increased to 258,084 miles, an increase of 387 per cent. That railroad mileage does not afford an adequate index of the growth of transportation may be seen from the fact that between 1890 and 1925 while mileage increased only about 50%, revenue freight ton miles increased no less than 448%, or more than eight times as fast.

The enormous expansion of our manufacturing industry during that period is shown in Census Bureau reports, which place the value added to products by manufacturing processes in 1869 at $1,395,000,000; and in 1923, the last year for which figures are available, at $25,850,000,000, or an increase of 1,760%.

Even this evidence of industrial growth is surpassed by the record of bituminous coal, which during the same 50 years, comparing the average for the first 10 years of the period with the average for the last 10 years, increased in production from 20,303,000 tons to 507,803,000 tons, or 2,400%. Decade over decade during that period the increases were as follows:

For the second decade, 152%; for the third decade, 82%; for the fourth decade, 118%; for the last decade of the period, 56%.

The last decade referred to includes the years of the World War, and I call particular attention to the creditable way in which the industry responded to the demand of the nation for fuel during that critical time. The heatless Mondays of the winter of 1917-18 were made necessary by transportation difficulties and not by mine disability. Although the development of new mines is not ordinarily a matter of days or weeks, but of months and even years, yet the bituminous output of the country for 1918 reached a total never equalled before or since.

To help visualize the volume of coal production in that year, let me point out that if it were used to build a modern Tower of Babel, covering one acre of ground, the tower would reach 100 miles into the air; or if it were loaded into railroad cars, it would make a train extending more than four times around the earth; or, yet again, it would cover an entire township of 36 square miles with a layer of coal more than 23 feet thick.

The end of the war saw a sudden check to the rate of increase in the use of bituminous coal. For the six years from 1920 to 1925, inclusive, the average output was only 5 per cent. in excess of that for the decade 1910 to 1920. This check was partly due to oil and hydroelectric competition, but the large portion of it must be attributed to the development of more efficient methods of utilizing the coal itself.

The indications are that the growth in demand is beginning to outstrip the economies in utilization and also the use of petroleum and hydroelectric power and that we are entering upon another period of pronounced increase in coal consumption from year to year.

From this statement showing the expansion of American industry and the increase in the production of bituminous coal during the last half century, it may be seen how adequately the bituminous mining industry has met all the demands laid upon it by our rapid growth in manufacturing and transportation. It remains to point out that the fuel has been furnished with great regularity and at low mine prices.

Interruptions in the supply of bituminous coal are never brought about by any technical difficulties in the operation of the mines. At all times there has been adequate mine capacity to meet all demands. Interruptions in production due to causes within the industry occur only in case of labor difficulties; interruptions in supply to consumers sometimes have been caused by the failure of our transportation system to move the coal offered it. This latter source of interruption was particularly prevalent during the years immediately following the war, but as a result of improvements in railroad equipment and management this has now become of rare occurrence and slight importance.

Strikes occurred not infrequently in the years before the war, especially during the negotiation of new wage agreements, but they seldom resulted in any serious interruption in the supply of bituminous coal. Formerly, district wage agreements expired on different dates and no miners' organization could enforce its demands by threats of freezing the people or crippling our entire industrial life. But the Government itself during the war, through the United States Fuel Administration, fixed a uniform expiration date for wage agreements in organized bituminous districts. Even under that unfortunate arrangement and in spite of the general industrial confusion incident to the transition from war to peace-time operation, the amount of interruption chargeable to the bituminous mining industry has not been great.

During the last eight years there have been two so-called general strikes in the unionized section of the bituminous industry: that of the fall of 1919 and that of the summer of 1922. The former lasted only six weeks and in itself caused practically no shortage of supply. The so-called runaway market of 1920 was not due to a coal strike, but to circumstances over which the bituminous industry had no control. The two most important contributing causes were the strike of British

coal miners and transportation inefficiency. The latter was accentuated by the switchmen's strike.

Although the strike of 1922 lasted for nearly five months, it affected only a portion of the industry and there was little actual hardship caused by lack of fuel. Even such shortage as did develop was due more to the coincident crippling of transportation by the shopmen's strike than to the decline in the mining of coal caused by the strike of the mine workers themselves.

Of the two occasions since the war—namely in 1920 and at the present—when there have been sudden increases in demand with some consequent rise in prices, neither was attributable either to a coal strike already in existence in this country or to fear of a strike in the future. In both instances, the immediate cause was a sudden increase in the demand for bituminous coal for export to foreign lands; and on both occasions this increase in foreign demand was due to a coal strike in Great Britain, where the coal industry has been legislated nearly to death.

In a normal year our overseas exports amount to slightly more than 4,000,000 tons. In 1920, when such exports were increased to nearly 20,000,000 tons, the increase in the production of bituminous coal over the normal annual output far exceeded that amount. Similarly during the present period of abnormal foreign demand, when overseas exports for the first ten months of 1926 have exceeded normal exports by something over 12,000,000 tons, the increase in bituminous production has again far exceeded the increase in exports. It is also true that during the anthracite strike in the fall and winter of 1925-26, the increase in bituminous production over normal was in excess of the deficiency in anthracite production.

This record is a splendid tribute to the ability and readiness of the bituminous industry to meet any unexpected demand for its product. The present large output, which at the moment is running at the rate of nearly 700,000,000 tons a year, would have been impossible, however great the world's need of coal, if the capacity of our mines had been limited to our normal yearly production of 500,000,000 tons. It is fortunate for the public that extra mine capacity is available, whether in times of war or of peace.

Of equal importance with regularity of supply in a well functioning industry is reasonableness of price. In this respect again the performance of the bituminous mining industry is one for which no

apology is necessary. Government reports show that from 1880 to the outbreak of the World War the mine price of bituminous coal was very low and remarkably constant.

The war period brought a rise in the cost and selling prices of practically all commodities. Coal was no exception. The increase in mine prices is accounted for by an increase in the cost of operation, of which labor cost constitutes nearly 70%. America's industrial development was made possible by these low mine prices, which continue to be lower than those prevailing in any other industrial country of the world.

It must be borne in mind that industrial consumers of bituminous coal do not increase their purchases appreciably by reason of any reduction in price, nor will higher prices materially reduce the consumption of coal. When the price is low many buyers do not contract for their fuel supplies on the theory that the market will go still lower or that coal is so plentiful that proper stocks need not be carried; hence when a demand from an unexpected quarter causes a little flurry, the market is crowded with buyers, many of whom attempt to buy far beyond their immediate needs. In other words, psychology has great influence, and fear of an approaching scarcity, whether well founded or not, has almost as much effect upon prices as an actual shortage.

An advance in price is a sure stimulus to an increase in production, which is after all the only remedy for a shortage of any product. The industry has met the present situation by rapidly increasing its weekly output from an average of 9,500,000 tons in June to a record production of 13,400,000 tons in the last week of October. This increase, it may be noted, is nearly equal to the normal weekly production of Great Britain.

The conditions under which mines are operated present peculiarly difficult technical problems. In a manufacturing establishment operations are concentrated and carried on in the full light of day. In the designing of the plant, operations can be planned in a way to secure most economical performance. Mining, on the other hand, is carried on in underground darkness. The operations must follow the veins of coal over widely scattered areas.

There was a time when all the operations around a coal mine were performed by human labor. The coal was mined by hand, was carried to the mouth of the mine either on the backs of men or on small cars

pushed by men, and, where hoisting was necessary, was raised by means of a windlass turned by hand. The process of mechanization has been going on for many decades. How great an advance has been made may be seen from a mere enumeration of the more important changes that have taken place. Somewhat in the order of their development have come mechanical hoisting; haulage, first by horses and mules, then by locomotives; mechanical drills; cutting machines; conveyors and loaders. Some of these devices have already become practically universal in all progressive bituminous coal mining districts, while others are just coming into use. As a typical example of the progressiveness of the American coal mining industry in this respect, I mention the extent to which coal-cutting machines are utilized here and in Great Britain.

In 1907, the coal cut by machine in the United States was 35% of the production, while the percentage in Great Britain was but 5%. In 1924, the comparative figures for coal cut by machine were 70% for the United States and less than 19% for Great Britain.

The social interest in the extent to which labor-saving mechanical devices are utilized in every industry arises from the fact that such devices lessen the cost of production and in turn the price of the product. With all due allowance for favorable mining conditions here and the energy of the American people, the superiority of our industry in supplying industrial fuel at a low cost must in part be attributed to the enterprising readiness of mine operators to develop and utilize labor-saving devices.

Our output of coal per man employed in the industry stands out in striking contrast to that of other countries. Thus in 1924 the average yearly output per man was: In Belgium, 152 net tons; in France, 167 tons; in Germany, 234 tons; in Great Britain, 246 tons; and in the United States, 734 tons. The output here per man employed in the industry is almost exactly three times that of Great Britain, our nearest rival. There is at the present time a lively interest in the mechanization of mines among operators of the country, due to the highly competitive condition of the industry, which can be relied upon to bring about the still further use of labor-saving devices.

I must refer briefly to another phase of mine operation which is receiving much attention and in which great improvements are under way, namely, the careful preparation of coal by the operator and the

assistance given by him to his customers in selecting suitable coal for different purposes. Many companies are devoting fully as much attention to possible improvements in this direction as to the introduction of more efficient underground machinery.

Only in a limited sense has the mine operator completed his service through the efficient operation of his property and the adequate preparation of the product. Bituminous mine operators fully realize that it is to their interest to give all possible assistance to those engaged in efforts to improve the utilization of coal. Earnest consideration is being given to automatic stokers for industrial and domestic use, briquetting, gasification, low temperature carbonization, the utilization of by-products, the use of pulverized coal and other lines of development. They look forward to the time when the more convenient and more efficient combustion of their product will lead to a great expansion in its use.

By this analysis of the history of the bituminous mining industry the following facts have been established:

First: The rapid growth of American transportation and manufacturing industries has been possible only because the bituminous coal mining industry has met all demands upon it for industrial fuel.

Second: It has furnished that fuel at mine prices always lower than those in competing countries.

Third: The industry has led the mining world in its readiness to adopt mechanical devices which make for labor saving.

Fourth: The industry is keenly alive to every possibility of reducing costs of production, improving methods of preparation and promoting more efficient utilization of its product.

Fifth: These truths about its history and its present attitude justify the opinion that in the future, as in the past, it will efficiently meet all fuel demands made upon it.

In view of this creditable record, it is difficult to account for agitation for the enactment of Federal regulatory legislation. This agitation during the past year has been largely an aftermath of the recent anthracite strike.

There has been some advocacy of regulation of the industry because of irregularity of operation, due to seasonal demands. The effect of this normal degree of irregularity of operation may be easily overestimated, but it must no be forgotten that the cause is to be found not within the industry itself, but in the buying customs of those whom

it serves. Irregularity of operation is due to irregularity of demand. If this irregularity is to be abolished or reduced by legislative fiat, the regulation must be applied to coal consumers, rather than to coal producers.

Some advocate Federal interference on the ground that it is necessary to safeguard the country from the effect of strikes. I have already pointed out that there have been very few occasions during which there was any noticeable interference with our bituminous coal supply. Furthermore, at the time of the strike of 1922, at least 60% of the bituminous production of the country was coming from union mines, but since then a change has taken place. During the past summer approximately 70% of the entire output of bituminous coal was produced in non-union mines. For that reason the danger of serious interruption in supply through cessation of work by union labor is less today than it has been at any time since the organization of the miners' union.

The relations between miners and operators have never been more friendly than they are at the present time. Employers in this great industry are keeping pace with other American employers in caring for the welfare of their employes, and a growing consciousness on the part of the men that their interests and those of the operators are one, is creating a sentiment of mutual understanding and cooperation. The most promising outlook for future peace in the industry lies in permitting present tendencies to develop without interference from governmental agencies.

The arguments for Federal control of the bituminous mining industry would apply with equal force to other industries. The reliance upon governmental bureaus instead of individual initiative, the substitution of artificial regulation for the operation of natural economic forces, and, most of all, the intrusion of politics in a purely industrial field and one which the complexity of operation renders particularly unfit for bureaucratic control, could result in nothing less than impaired initiative, diminished productive effort and higher costs to the coal consumer.

Proposed governmental interference with the bituminous mining industry is unjustified. My presentation of the history and present condition of the industry has indeed been inadequate if I have not convinced you that its record entitles it to public commendation. It has

proved itself capable of meeting any unexpected demands for its product by a rapid expansion of its operations; it has furnished the nation with an adequate and remarkably constant supply of fuel at the lowest mine price found in any country; it has been able to perform this service because of its readiness to adopt all mechanical devices and all improvements in methods which would lower its cost of production; it is devoting much attention to the development of more efficient ways of utilizing its product. An industry with such a record of past performance may be safely left free to work out its own problems and direct its own future development with the confidence that individual initiative and enterprise will, if unhampered by governmental interference, render the industry increasingly efficient.

THE COMING OF THE NEW COAL AGE

By Edwin E. Slosson, Director
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The present International Conference on Bituminous Coal marks the opening of a new era in the utilization of coal. For here and now are being discussed as actual operations processes and projects which a few years ago were purely theoretical and commonly considered chimerical. In talking of the "Old Coal Age" and the "New Coal Age" I am not referring to the Carboniferous Period and the later deposits, for I am here concerned not with the formation of coal but with its consumption.

In the Old Coal Age, which has lasted now some 600 years, we knew nothing better to do with coal than to burn it. But in the New Coal Age now opening we have found that coal can be put to better purposes than to be burnt in its crude state; that when we use it merely as a fuel we are losing compounds that may sometime be worth more to the world than the heat obtained. We are beginning to realize the value of coal as a source of raw material for the synthetic chemist. I am of course concerned with bituminous coal. Anthracite is not nearly so useful from the viewpoint of the chemist.

In 1306 King Edward I issued a proclamation making the use of coal as fuel in London a capital offense and one man was executed for the crime. Five hundred years later Colonel George Shoemaker was threatened with arrest for attempting to sell a few wagon-loads of coal in Philadelphia. When it was first proposed to burn coal by piecemeal, using the gas for lighting and then the coke for heating, the idea met with furious opposition. Scott, Byron and Napoleon were among those who made fun of the crazy notion. A German paper in 1816 (Koelnische Zeitnung, March 28) condemned the project of street lighting on six points: (1) Theological, as blasphemous since God had divided the light from the darkness; (2) Juridical, people should not be compelled to pay for gas they do not want; (3) Medical, the emanations were injurious to health and people would stay out late and catch cold; (4) Moral, the fear of darkness would vanish and crime would in-

crease; (5) Police, the street lights would frighten horses and embolden thieves; (6) Economical, great sums would be sent to foreign countries.

The use of coal in locomotives and steamships was likewise condemned and ridiculed on the start. In 1804 the British Admiralty declared it their duty "to discourage the employment of steam vessels as . . . the introduction of steam vessels was calculated to strike a fatal blow to the naval supremacy of the Empire." Yet in spite of this warning from the highest authority the British Empire has somehow managed to survive the introduction of steam navigation.

We laugh at the people of six hundred years ago because they thought that coal was not fit to burn. But will not the people of six hundred years hence laugh at us because we thought that coal was fit for nothing but to burn? We look back with scorn to the time when efforts were made to prohibit or restrict the burning of coal as it is carried on today. But may we not look forward to the time when efforts will again be made to prohibit or restrict the burning of coal as it is carried on today? In fact, capital punishment has already been advocated, though in jest, for such a crime of wastefulness. The Secretary of the British Royal Commission on Oil Fuel, Admiral Dumas, said not long ago: "I would like to see a government official hanged at every lamp-post where gas is burned because benzol goes up with the flame." He had in mind the impending shortage of gasoline for which benzol, otherwise known as benzene, is a suitable substitute as motor fuel.

President Baker is more sanguine, although less sanguinary, in his predictions, when he said in his opening address: "In less than a generation the present methods of shipping coal to be burned in its raw state under boilers hundreds of miles from the mines will appear to have been primitive and rudely unscientific."

It is hard to be prophetic at this Conference. Several speakers after telling what might be done have been disconcerted by being told by some one in the audience that it has been done. I am in the same embarrassing situation. I hesitated putting into my paper what I have said above about penalizing the burning of raw coal so I put it six hundred years hence for safety's sake. But this afternoon M. Jean Bing told us the French Government had considered and the Italian Government had adopted measures to restrict this wasteful practice.

The familiar phrase for anything particularly expensive or extravagant, "It costs like smoke," implies doubtless an unconscious realization of the fact that oxidation is the reversal of the synthetic reaction, the undoing of the constructive activity of animate nature. The plant builds. Man utilizes. Fire destroys. Now one of the most wasteful forms of smoke was that which poured uninterruptedly during the great part of the last century from the open tops of the beehive coke ovens. In fact one can yet see these prodigal flares on the Pennsylvania mountains as he looks out of his Pullman window in the night. Now this is not merely a waste of fossil fuel, which we already begin to realize will not last forever, but there is also a loss of a variety of compounds that can be made very useful if properly worked up. If a ton of bituminous coal is heated in a closed retort, instead of the open beehive, we may get besides the gas and the coke a dozen pounds of ammonium sulfate and a dozen gallons of tar. The ammonium sulfate is valuable for a fertilizer since it will feed nitrogen to the crops and the tar on redistillation will yield a dozen products out of which some 200,000 distinct organic compounds may be made, some of which are extremely useful to mankind.

The war has taught the United States a lesson in economizing the by-products of the distillation of coal. In 1913 nearly three-fourths of our coke was made in beehive ovens which wasted the tar, ammonia and light oils. In 1925 the ratio was reversed and more than three-fourths of our coke was made in ovens that saved these by-products. Last year was the peak in American coal-tar production, over 528,000,000 gallons, but sixty per cent of the tar so recovered was afterwards consumed as fuel instead of being worked up into chemical compounds.

Mr. Crawford has shown us that in the steel plant tars can be easily and cheaply stripped of their phenols and cresols to supply domestic needs without materially reducing the fuel value of the tar. Yet the burning of untreated tar is on the increase in our country.

In the old days before the war when men wanted to get more gasoline than petroleum contained they knew no other way to get it than to smash up the big molecules into little ones, to break down the heavy oils to make light oils. This "cracking" process was regarded as a great achievement in its day and quite rightly since we could be running few automobiles without it. But the world is passing

into another era now, the age of synthesis, when the chemist will build up instead of breaking down. Starting with the commonest and cheapest materials, air, water and coal, the chemist can construct at will all sorts of valuable compounds for which we formerly had to rely upon nature if indeed we could find them at all.

The veteran French chemist, Professor Paul Sabatier, of Toulouse, opened the door to the new era with the key called "catalysis." Before the end of the last century he found that hydrogen gas could be made to unite with carbon monoxide gas in the presence of finely divided nickel and produce methane, well known in natural gas. Now these two constituents, hydrogen and carbon monoxide, are easily made by passing steam over redhot coal, the "water gas" process. Many other metals and compounds have since been found to act like nickel as a catalyst, that is, they speed up a process by their presence without being used up or appearing among the products.

The building blocks used by the synthetic chemist in this new game he is playing are mostly the four ordinary elements, carbon, hydrogen, oxygen and nitrogen. We may combine their initials and call these constituents CHON for short. Nitrogen and oxygen have been impartially apportioned by Providence to every country in exact proportion to its area. Hydrogen may be obtained from water which heaven showers upon most lands in sufficient abundance. Carbon also is distributed equally and freely in the carbon dioxide of the atmosphere but in such minute amount that we must employ the plants to collect it for us, especially those which lived in the carboniferous period when vegetation was more abundant and worked cheaper than it does today.

To effect the liquefaction of coal all that is necessary is to add water to it. But this is not a problem in simple addition, like dissolving a lump of sugar in a cup of coffee. It involves linking up electrons, and usually heat, pressure and a catalyst are needed to effect the union of the atoms.

What kind of chemical compounds might be made from the coal, air and water? Obviously all the multifarious substances composed of these elements that exist in the three kingdoms of nature, animal, mineral and vegetable. We have the same raw materials to work with as the plants and animals and the same source of energy,

and we ought to be able to make anything that is made by any living creature if we only knew enough. But we can go much further and make hundreds of thousands of carbon compounds that never existed until they were invented in the laboratory.

It has recently been demonstrated to the surprise of the commercial world that methanol may be made from coal and water. Methanol is the same liquid as has hitherto been commonly known as "methyl acohol" or "wood alcohol," but this name has been the cause of frequent and sometimes fatal confusion by those who think all alcohols are fit to drink. Ethyl alcohol looks very much like her smaller sister methyl, but the two can be distinguished by their physiological reaction on the human system. Ethyl may make a man blind drunk but methyl may make him drunk blind. Methanol in its proper place, which is outside the human stomach, is a useful article in many manufactures and some eight million gallons have been made in America annually by the distillation of wood. But this method of manufacture is now hard hit by a new and cheaper process developed in Germany which uses water-gas as the raw material.

Various other alcohols, such as butyl alcohol, made in America by fermenting corn are made in Germany from water-gas. Such liquids are finding a new and extensive field as solvents for the cellulose lacquers which are being use don automobiles and furniture. They are likely to displace in large part the paint and varnish which have been employed from time immemorial since they can be either sprayed or laid upon a surface, that is, applied either with the air brush or the hair brush.

The water-gases that in some sections of the United States are still allowed to escape from coke ovens unused are at the mines of Bethune, France, cooled and condensed and utilized for making methane, benzene, ethyl alcohol and ammonia.

Owing to the catalytic process for synthetic ammonia invented by Fritz Haber, Germany is now exporting fertilizer instead of importing it as before the war. About 425,000 tons of free nitrogen from the air is now fixed for fertilizers by catalysis every year, and this takes the place of 2,700,000 tons of Chilean nitrate. But Muscle Shoals still stands idle.

Benzene, which can be made from coal in various ways, is the mother substance of the aromatic family of chemical compounds, a

family of over a hundred thousand and rapidly growing. Among these are the aniline dyes and drugs that have made the world brighter and safer in our generation. One of these synthetic products, carbolic acid, is familiarly used as an antiseptic and is nearly as useful though much less familiar as one of the two components of bakelite. The other component, formaldehyde, is also an antiseptic and also made artificially. If such synthetic resins could be cheapened as much as General Patart foresees they would be used for the finishing and furnishing of houses and find innumerable and inconceivable other applications.

The chief stimulus to such investigations in Europe is the search for home-made motor fuel. We Americans are not interested in this question now but some day we shall be, and meantime it is interesting to watch their chemists trying to see how many different things they can make out of common coal, like children playing with the Chinese tangram.

When kerosene first came into use as a lamp illuminant it was called "coal-oil," for it used to be supposed that petroleum had somehow been formed from coal. Later that theory was called in question, and geologists are still disputing the origin of oil. We seem likely to use it up before we find out where it came from. But even if coal-oil turns out to have been an inappropriate name in the past, it may prove to be true in the future. For petroleum can be made from coal, and some day we may all have to make it that way.

For the less oil we have the more we use. The lower the supply in the ground the higher the output of our refineries. This increase in consumption can not keep up forever, however liberally you may estimate our unseen supply underground.

The countries that are short on petroleum are already contriving substitutes. The Germans, who were well supplied with coal but had little oil before the war, began experimenting on methods of making artificial petroleum. Since they have lost some of their best coalfields through the war and oil is harder to get than ever, they have been still more active in such research, and how successful they have been we have heard at this conference.

Theoretically it is simple enough. Petroleum is a mixture of compounds of hydrogen and carbon. Just hitch up these two elements, and there you are! But there are other hitches in the

proceedings. Either carbon or hydrogen will unite readily with oxygen, but they have little liking for each other. Only when stirred up by high heat and forced into contact by high pressure will they combine. Under these conditions the carbon and the hydrogen gas unite in all sorts of ways and form gaseous liquid and solid products of various usefulness.

The coal for this process does not have to be of a special quality as is required in making gas or coke by our present methods. Any kind or form of coal can be used, and high yields of the hydrogenated products are said to be obtained from the brown coal and lignite of which the United States and many other countries have an abundance. Peat may thus be worked up to gasoline and other marketable compounds—also pitch, tar, sawdust and any vegetable material.

When the first trolley car ran down the street of Atlanta, Georgia, an old negro watching the mysterious vehicle from the sidewalk was heard to remark: "Dese Yankees is quah people. Fust dey come down heah and free de slaves; den come down and free de mule."

That is a good summary of the progress of civilization. The first animal that man enslaved was man. Next he shifted the burden in part to the back of the ox and the horse. Now human slavery is at an end and we are gradually getting to the point of releasing the lower animals from their enslavement. Eventually all the hard work of the world will be done by engines run by inorganic power.

Modern civilization is based upon such utilization of inanimate energy. The number of people who can live on the earth and the comfort in which they live depend upon how much energy can be obtained and how economically it may be employed. Of all conceivable sources of energy only the sun's rays are actually available and these not directly. Until some practicable solar engine is invented we must rely upon indirect means of making the sunshine work.

The energy radiated by the sun reaches the earth through 92,000,000 miles of empty space as cold as can be. When the rays come into our atmosphere they heat up the air and so set up currents in it. That gives us power for windmills. When the rays strike the sea they heat up the water and evaporate some of it which, carried away by the wind, falls on the mountains as rain. That gives us power for our water-wheels. When the rays fall on a green leaf they are set to

making cellulose. That gives us fuel for our engines. There are then three ways in which to engage solar energy, two physical and the third chemical.

I suppose the first employment of external energy in the history of the world was when some prehistoric savage discovered that he could save himself walking by floating down-stream astride of a log. Doubtless the second was when some other genius discovered that he could make the wind propel his log canoe across still water by hoisting a skin as a sail. The third method, the chemical process of using solar energy, came with the invention of the steam engine a hundred and fifty years ago.

The chemical means of utilizing sun power, that is, combustion, is at present our chief dependence, but the little green leaves work too slowly for us. They cannot keep up the pace that modern life demands. So we have drawn upon fossil fuel, upon the carbonaceous accumulations of the Paleozoic period. The iron horse feeds on subterranean pastures. We stoke our engines with the giant ferns and mosses that grew in Wales or Pennsylvania long before human life began.

In the green laboratories of the curious vegetation of that remote era the light waves from the sun acted as they do today, dissolving in the plant the bonds that connected the carbon, and restoring the oxygen to the air. We now reverse the process and reunite the carbon of the coal beds with the oxygen of the air and so revive the sunshine that fell upon the earth millions of years ago.

But we have for a century been living upon our carbonaceous capital. We have skimmed the cream of our coal beds and wasted about 99 per cent of its power. The concentrated fluid extract of fossil fuel, petroleum, is even more limited and has been still more recklessly wasted. Coal is scarce in many parts of the world and oil will soon be scarce everywhere. The southern hemisphere is conspicuously deficient in coal. Africa, South America and Australia have not enough for their own needs and will have to borrow from their northern neighbors.

The most obvious distinction between plants and animals is that the former have roots and the latter have legs. Plants are mostly sessile; animals more or less mobile. Man, having only two legs and being devoid of the wings of the birds and the caudal propeller of the fish, is at a natural disadvantage compared with the migratory members of the animal kingdom, but in the twentieth century he has surpassed

them all and raised himself farthest above the vegetable stage. By the aid of his engines he can now outfly the eagle, outswim the fish, outpull the elephant and outrun the deer. This new freedom he has employed unprecedentedly in tourist travel and mass migration.

The mobility of modern man is due to his tapping of subterranean stores of fossil fuel, coal and oil. The expansion of Europe is based upon the expansion of gases. The power of the peoples which now dominate the world in war and peace is the pressure of mutinous molecules, released from bondage. Modern civilization is based upon atomic anarchy. This is the force that in war propels the cannon ball and explodes the shell, and in peace pushes the piston of the steam engine and the automobile. Steam reigned undisputed for about a century, say from 1776 to 1876. After that date came the internal combustion engines which were more efficient and compact since they produced pressure by the explosion of their own fuel and needed no firebox or boiler: the Otto engine using gas in 1877, the Daimler engine using gasoline in 1892, and the Diesel engine using crude oil in 1897. These made possible in the twentieth century the airplane and the automobile, the motor-boat and the motor-cycle, the tractor and the tank, and gave to shop and farm a convenient motive power requiring no engineer or fireman.

The mobility of man is measured by the mobility of the power he employs. Consequently, the efforts of technologists are now directed toward increasing the fluidity of fossil fuel. The finer the particles the more fluid the form. The cheapest and most abundant source of energy is coal, but this is solid and deeply embedded in the rocky matrix of the earth's crust. From this matrix the coal has to be torn loose by explosives and then broken into lumps small enough to be shipable and to be shoveled. By putting fuel into powdered form it can be blown into a furnace on a blast of air. But combining it with hydrogen we can reduce the carbon to a liquid form and by heat convert it into a gaseous state where all the molecules are free and independent.

But the atom is not the limit of divisibility, although that is what its name implies. As we now know, it is possible to break up the atom, and its finer fragments, electrons and protons, afford us a still more fluid form of energy, the electrical current. To transport solid coal from mine to the factory requires a large part of its power. To transport water from the mountain to sea requires no power. It will flow

down hill of its own accord if you will only provide it with a sloping channel or an empty pipe. To transport electricity from a point of high potential to a point of low potential requires no power. The current will flow down hill of its own accord if you will only provide it with what is for it an empty pipe, that is, a copper wire. And the electric current will travel far faster than the coal train or the flowing stream. So the efforts of inventors are now concentrated on methods of increasing the mobility of energy by such means as converting coal into a liquid form, or converting its energy into the electrical fluid.

The greatest scientific achievement of the nineteenth century, in the opinion of those who lived in that century, was the formulation of two fundamental physical laws of the universe, the conservation of mass and the conservation of energy. According to these, matter and energy were immutable in amount and neither could ever be created or destroyed in the minutest measure.

But the twentieth is an unsettling century. Such mental revolutionists as Einstein, Planck and Bohr have opened our eyes and widened our outlook. We cannot be so cocksure about many ideas as were the simple-minded scientists of the former century. Some of the generalizations which seemed to them absolute and universal principles of nature appear to the more critical eyesight of the present generation to be disguised definitions; similar, as Eddington puts it, to the Great Law to which there is no exception, that there are three feet in every yard.

For instance, the law of the conservation of energy. We see a lump of burning coal giving off energy at a great rate as radiant heat and light. Where did that energy come from? Where was it when the lump was cold, if no energy can be created in the course of combustion? The reply of the nineteenth century chemist was clear and decided. The energy was there all the time in exactly the same amount, although its presence could not be demonstrated because it was in the form of "potential energy." Obviously this was unanswerable as an argument, although not very enlightening as an explanation. We are nowadays disposed to suspect that this "potential energy" was put into the coal by logic rather than by geology, and that if it exists in nature at all it is in the nature of the human mind. The twin laws of the conservation of matter and energy are as useful as ever, for they still serve to clarify our conceptions and to guide our experimentation. No experiment has ever been able to detect the slightest flaw in them, and it may never

be possible to devise tests so delicate as to disclose any discrepancy. Yet neither law is now regarded as absolute in itself and it seems that we shall have to substitute some general law which will include the two and allow for the transformation of matter into energy and *vice versa*. Einstein has worked out the formula for the equivalence of matter and energy, so we can now calculate how much heat will be produced if a certain mass of matter is annihilated. This idea has been welcomed by the astronomers, who have been hard put to it to devise means of keeping up the furnace fires of the sun as long as mankind would like to live. They have now figured out by Einstein's formula that the sun is losing weight, through the destruction of its material and the emission of immaterial energy, at the rate of four million tons a second. But even though wasting away at this appalling rate the sun can hold out for ten million million years.* This gives a welcome extension of time for the life of our world, and permits us to hope that we may get our social system perfected before we all become Eskimos.

This principle of the interchangeability of matter and energy must apply to all chemical reactions where heat is produced or absorbed. Wherever coal burns there matter is being converted into radiant energy. Wherever a green leaf grows there matter is being manufactured out of solar energy. In such cases of course the quantity of matter or energy transmuted is too small to be demonstrated. In the burning of coal the heat evolved means a loss of about one part in ten billion of the joint mass of the carbon and oxygen combined. But this loss of matter becomes appreciable when we consider the world-wide consumption of coal. If we assume that all coal is pure carbon and that the combustion is always complete, the carbon dioxide produced by all the coal that burned in a year throughout the world would weigh about five billion tons. This would involve a disappearance of matter amounting to half a ton. The substance of the world is therefore being slowly consumed by the combustion of coal. But such loss is continually being replenished by the sunshine that falls upon vegetation and is there fixed in the form of cellulose.

The problems discussed at this conference are world wide questions in which the whole human race is concerned, for they deal with the subterranean stores of wealth-producing energy which are the common inheritance of the population of the planet. These treasures are limited

* Heyl, Fundamental Concepts of Physics, p. 72.

and irreplaceable, and upon them our modern civilization is supported. The main question, and the only one with which science as such is concerned, is to see that this endowment of fossil fuel is not wasted but utilized to the greatest advantage of the present generation and posterity. Who owns it, and who makes the most money out of it, are minor matters that do not affect the main question. Germany lost a large part of her coal trade through the world war. England lost a large part of her coal trade through the labor war. But neither of these affects directly the coal that is still in the ground. Coal is coal whether it is dug by Germans, British or Frenchmen, or as in the case of American mines, by all the races of Europe working together.

The nation that deserves the most credit is that which makes best use of its share of fossil fuel, and making the best use of it does not mean using it up fastest. We owe a duty to posterity, and we condemn a spendthrift father who dissipates his fortune and leaves his son destitute. When we learn that sixty per cent of the coal-tar produced in the United States is burned for fuel we feel that something is wrong, but we do not know how to remedy it. We cannot compel a man to save by-products that he cannot sell or to work land that does not pay. The frequent admonition of a mother to her child at table: "Eat your crust. Some day you may be starving and be glad to get it," is not convincing. The normal child cannot conceive of ever being hungry enough to eat that crust, and he cannot see how eating the crust now would provide it for him on that hypothetical day of destitution. We cannot store up unusable stuff for an indefinite future nor refuse to make use of our buried treasure for the present needs, on the ground that our grandchildren may make more out of it.

There is no world organization that can exercise the right of eminent domain over natural resources and compel a country to stop wasting its coal and oil, or to employ its unused land and water-power. But all the same, and all the more, we should all rejoice when anyone discovers how to make a profit out of a waste product or how to make a process more efficient. When a way is found to convert a low grade lignite into a high class motor fuel, or to make manufactured alcohols and acids of the gas that used to flare from the tops of blast furnaces, or clear the air of our industrial towns, or to raise the efficiency of a fuel by low temperature carbonization, he has thereby benefited the human race, living and to come, whether he makes money

out of his patent or not. All knowledge goes ultimately into a common pool from which every man may draw what he can use. Pure science is essentially international, although, however, it may be nationally applied. That is why we can have an International Conference on Bituminous Coal in which representatives of different nationalities and of rival commercial interests unite to promote the general welfare of the world.

THE SYNTHESIS OF PETROLEUM

By Franz Fischer

Director of the Institute of Coal Research,

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The purpose of my lecture is to give an illustration of the synthesis of petroleum hydrocarbons at ordinary pressure as it has been carried out by Tropsch and myself. I wish to give this within the limits of the whole problem of the liquefaction of coal.

Decomposition of Coal by Heat

It is possible to produce petroleum-like products from the bitumen of coal, peat and oil-shale, and from waxes and fats by decomposing these materials through distillation at low temperature with or without pressure. I need to remind you only of the well-known distillation of fish-oil under pressure, which Engler performed and applied to his theory of the origin of petroleum. But as a substitute for natural petroleum which is lacking in many countries these raw materials can only partly be taken into consideration, and, at any rate, it is not a question in this process of synthesis in the stricter sense of the word, that is, of the combining of smaller particles; but principally a question of a breaking up of the larger molecules into smaller ones, thus not a composition, but a decomposition. However, it is by no means our intention to say anything against the practical importance of the distillation of bituminous coal at low temperature. On the contrary, we are convinced of its great future. But in the methods of distillation the resulting low temperature tars or oils are quantitatively only by-products of the process. Quantitatively the chief product consists of the residues of distillation, that is, of the semi-coke upon whose possible utilization the further development of these processes depends; this is in the field of cmokeless fuel, of powdered coal and of water gas. An industry that intends to manufacture petroleum-like products as

its chief product, must, however, pursue a different course. The application of heat alone is not sufficient.

Decomposition by Hydrogenation

If one attempts to obtain petroleum-like hydrocarbons from unaltered coal there can be considered, at present, only the action of hydrogen at high pressure and at high temperature. In this case, not only is oxygen probably withdrawn and hydrogen added to the different kinds of molecules of which the coal is composed, but there takes place along with the decomposition of the molecules and the hydrogenizing a reduction in size of the large molecules of the coal originating from the humic acids. The products of this process are hydrocarbons with the most varying boiling points, and liquid substances containing oxygen.

Berthelot, the centenary of whose birth will be celebrated next year, more than fifty years ago, was the first one who proved the possibility of transforming coal and wood into hydrocarbons by hydrogenizing. In doing this he made use of the general method of hydrogenizing, perfected by him, with concentrated hydriodic acid under pressure. His results are of great scientific value, but, naturally, on account of the materials used, have no practical importance.

Bergius and Billwiller succeeded in 1913 in solving the problem of the conversion of coal into petroleum-like products in a way which is industrially practicable. In this, as is well known, one proceeds with hydrogen under a pressure of about 200 atmospheres and at temperatures of from 400° to 500° C., and one obtains up to 50% of the weight of the coal in a tar-like oily mixture and gasoline. The main part of the mixture, namely, the hydrocarbons, are predominantly of cyclic and, to be more specific, of hydro-aromatic character. The smaller part of the oil mixture consists of aromatic substances containing oxygen, viz., phenols. According to the statement of Bergius, also the low-boiling parts, the gasoline of his method, consist of hydro-aromatic compounds.

It is not my task to go into details of the well-known Bergius process. But I should like to point out the fact that, corresponding to the cyclic structure of the humic parts of coal, there are obtained as products of the hydrogenizing decomposition in the Bergius process chiefly substances of a cyclic structure. This corresponds very

well with our observers, that oxidation of coal under pressure yields up to 30% acids of benzene carboxylic character; which fact Wheeler and also Bone verified a few years later.

The hydrogenation under high pressure of Bergius and Billwiller begins, thus, with unaltered coal and ends with a mixture of cyclic compounds.

HYDROGENIZING SYNTHESIS

Contrary to this method, not only in regard to raw materials but also as to the manner of procedure and the products, are the building-up syntheses, namely, those methods which attempt to form from smaller molecules the larger ones.

Next I should like to present a short summary of the older syntheses for higher hydrocarbons as far as they interest us here. I refer you to Table 1.

TABLE I.

Synthesis of Higher Hydrocarbons from Lower Ones:

1866 Berthelot—C_2H_2 heated at atmospheric pressure; benzol and tar-like hydrocarbons.

1897 Sabatier—C_2H_4, Ni-catalyst above 300° at atmospheric pressure; mixture of gaseous and liquid hydrocarbons and a coal-like substance.

1899 Sabatier—$C_2H_2+H_2$, Ni-catalyst at atmospheric pressure; saturated gaseous and liquid hydrocarbons of petroleum-like character.

1906—Ipatiew—C_2H_4 polymerization under pressure at 400° to 500°; partially liquid hydrocarbons of the formula Cn H_2n.

As far as the practical working of the above methods for the building-up of the higher members of the methane series, that is, the real petroleum synthesis is concerned, they are too expensive and involved. And, in general, they did not start with as easily an obtainable raw material as carbon monoxide. The catalytic conversion of acetylene combined with hydrogenation according to Sabatier could still be used for the production of petroleum-like substances, if the price of acetylene would allow it. If this were the case, the much more simple polymerization of acetylene to ben-

zol could be resorted to for the production of motor fuels in a wider sense, although it turns out only partially in the desired direction.

HYDROGENATION OF CARBON MONOXIDE UNDER HIGH PRESSURE ACCORDING TO GERMAN PATENT 293, 787 (1913).

In the years following the methane synthesis of Sabatier and Senderens, Haber's high pressure synthesis of ammonia from nitrogen and hydrogen was carried out on a technical scale in the Badische Anilin und Sodafabrik. Therefore, it was quite natural to begin with the catalytic hydrogenation of carbon monoxide, using the exceptionally effective high pressure method. The German Patent 293,787 taken out in 1913 by the Badische Anilin- und Sodafabrik testifies to this fact.

For many years nothing was heard about the practice of this process; but from the patent it could be discovered that a mixture of hydrogen and carbon monoxide, with a surplus of carbon monoxide, was brought into reaction under pressure of about 120 atmospheres and at temperatures of about 400°, using different catalysts. From this a liquid reaction product resulted which was composed of an oily and a watery layer. The former consisted chiefly of hydrocarbons, which, according to the statement of the patent, were about two-thirds of a saturated character and one-third of an unsaturated character. In addition, they state that some dissolved organic compounds of oxygen of different kinds were present in the oily layer. By special purification methods, it is said, a product can be obtained which has a petroleum-like character.

The oily layer presented thus a mixture of different substances, which were not by any means homogeneous saturated petroleum-like hydrocarbons.

HYDROGENATION OF CARBON MONOXIDE UNDER HIGH PRESSURE WITH A SURPLUS OF HYDROGEN (SYNTHOL).

In our institute my collaborator, Dr. Tropsch, and I studied thoroughly the hydrogenation of carbon monoxide under high pressure. In order to avoid the easily occurring deposition of carbon by the so-called splitting of the carbon monoxide ($2\ CO = C + CO_2$), we worked, however, not with a surplus of carbon monoxide but, whenever possible, with a surplus of hydrogen. Alkalized iron proved to be the best contact substance. We found all kinds of new and par-

tially divergent results in comparison with the statements of German Patent 293,787. The most striking thing of it was that we, indeed, also obtained an oily and watery layer; however, the oily layer did not consist of hydrocarbons but almost exclusively of higher alcohols, ketones, and aldehydes, besides some higher fatty acids. For brevity's sake we gave the name of synthol to this mixture. A classification of the compounds discovered is found in Table II.

TABLE II.

Compounds Proved in 1923

Formic acid	Acetone
Acetic acid	Methyl ethyl ketone
Propionic acid	Propionic aldehyde
Isobutyric acid	Isobutyric aldehyde
Higher fatty acids up to C_8	Di-ethyl ketone
Methyl alcohol	Methyl and propyl ketone
Ethyl alcohol	Higher alcohols up to C_9
Propyl alcohol	Esters

The first report of our experiments we made at a session of our board of trustees in December, 1922. We published our results in the summer of 1923. Since we were concerned chiefly in our research work in producing liquid motor fuels from carbon monoxide, we studied principally the conditions necessary for the development of the oily layer, that is, for the production of the higher alcohols and ketones. We discovered, at that time, that the strength of the base, with which the iron contact was alkalized, is of influence on the degree of composition. With weak bases only the watery layer is obtained, which layer contains lower alcohols and ketones. Upon alkalizing with strong bases the composition was carried higher and higher. Starting with carbon monoxide we obtained, at that time, molecules with about nine atoms of carbon.

If I am to summarize briefly what new thing we discovered in the hydrogenation of carbon monoxide under high pressure in comparison with German Patent 293,787, it would be then, that with a surplus of hydrogen no hydrocarbons but exclusively products containing oxygen appear; certainly a surprising result; if one wishes to carry the synthesis to oily products, insoluble in water,

this depends upon the serength of the added bases; and finally we determined the accurate composition of the oily layer, the so-called synthol.

About a year after Tropsch and I had discovered that high pressure hydrogenation with a surplus of hydrogen does not produce any hydrocarbons but almost exclusively compounds containing oxygen, the Badische Aniline and Sodafabrik had already put into practice the high pressure synthesis of methyl alcohol. We ourselves were not interested in the synthesis of methyl alcohol, because we, as has already been mentioned, aimed to produce motor fuels out of carbon monoxide. For this purposes even ethyl alcohol is not well suited; still worse is methyl alcohol, with its small caloric value, since it is composed of fifty percent oxygen by weight. On the other hand we found that the higher alcohols which are present in the synthol can very well be utilized as motor fuels.

Hydrogenation of Carbon Monoxide Under High Pressure with Zinc Oxide as Catalyst (Methanol).

In the same year there appeared also investigations by Patart who, essentially verified our results, but announced at the same time that the hydrogenation of carbon monoxide with zinc oxide as catalyst at pressures exceeding 130 atmospheres and at temperatures below 400° stops at methyl alcohol.

Solely for the sake of completeness I mention here the production of methanol, the realization of which becomes quite simple when, as was published elsewhere, the presence of metals of the iron group and of strong bases is avoided. The fine thing about this process is that starting from carbon monoxide with the theoretical surplus of hydrogen, the methyl alcohol can be obtained directly almost free from water, and very pure.

It may, indeed, be said that in case of a synthetic process the production of homogeneous substances is favorable for its commercial value, and that the latter can be attained if only relatively valuable reaction products free from worthless ballast and of the greatest purity can be gained, so that a subsequent refining is not necessary. That a purification of the used gases from contact poisons, such as sulphur compounds, is usually required in case of all catalytic processes, is, to be sure, an impediment, but with the present develop-

ment of science and of technology only a very small one. This is largely counterbalanced, however, by the high degree of purity of the products produced.

Synthesis of Petroleum Hydrocarbons by Hydrogenation of Carbon Monoxide at Ordinary Pressure

Twenty-four years ago Sabatier and Senderens showed that carbon monoxide or carbonic acid could be reduced quantitatively to methane with the use of hydrogen, at atmospheric pressure, especially with finely divided nickel as a catalyst. This methane synthesis seemed to assume a practical importance soon after its discovery. The idea was, on the one hand, to convert in this fashion the carbon monoxide of illuminating gas, which is injurious to health, into methane, and on the other hand, to produce by catalytic treatment of water gas, a mixture similar to illuminating gas, but of a higher caloric value, which at the same time was to be free from carbon monoxide. What the reasons are why up to the present time a practical exploitation of the Sabatier-Senderens methane synthesis has not taken place on a larger scale may be left undecided now. Among other reasons it is probably because the methane produced is, for the most part, not so much more valuable than the water gas as to make the process pay.

My collaborator, Tropsch, and I have been working together for years in the domain of carbon monoxide in the most varied directions, and have finally found the way to produce, without use of pressure, the liquid and solid saturated hydrocarbons of the petroleum series from carbon monoxide and hydrogen. In this there appeared no compounds containing oxygen, while in case of the pressure synthesis of carbon monoxide with a surplus of hydrogen only products containing oxygen were made. It seems almost enigmatic that the excellent chemist Sabatier and his collaborators did not find the same twenty-three years ago. Perhaps it is because Sabatier studied above all the nickel catalyst, which is particularly well suited for the synthesis of methane, and that with reference to the temperature and the other conditions he preferred all that which was favorable for the formation of methane.

And just these conditions for the formation of methane are unfavorable for the synthesis of the higher hydrocarbons from carbon monoxide. We published one part of our results this spring, as far

as it seemed necessary for us to assure our priority in scientific research. I can add, however, that the worries that many people cause themselves with reference to the technical practicability of our synthesis do not oppress us. We solved the problem of the purification of technical gases in a simple manner, and the durability and possibility of regeneration of the contacts leaves nothing more to be wished. The fear has also been expressed that the apparatus would become too large if the work proceeded at atmospheric pressure. But from another side it has already been correctly pointed out that no one would think of performing the cheaply working contact process for the production of sulphuric acid under higher pressure in order to get smaller tube diameters and smaller apparatus. In this process, too, the gases must be freed of dust and contact poisons, especially from arsenic, and in spite of all this a kilogram of contact sulphuric acid can be produced for little more than a cent. But this is only by the way.

Since our publication in April we have conducted experiments to see whether there might be any difference in regard to the results and in regard to the durability of the contacts, when we used alternately synthetic gas and technical water gas purified according to our method. The synthetic gas was obtained by mixing electrolytic hydrogen with carbon monoxide, the latter being generated by dropping formic acid into heated concentrated phosphoric acid, thoroughly washing. The result of these comparative experiments was excellent, since both kinds of gases acted exactly in the same manner, not only temporarily but permanently. Thus we could continue with composure our experiments with the purified technical water gas.

On the other hand, we determined, that if only the hydrogen sulphide is removed from the technical water gas, the efficiency of the contacts is, to be sure, very much worse, but not completely zero.

It is seen, on the one hand, that our gas purification satisfies the most exacting demands, and, on the other hand, that it is necessary, if the excellent performance of the contacts is to be preserved.

As already mentioned we used chiefly water gas for our synthesis. But the proportion $H_2:CO=1:1$ is not absolutely necessary. Other ratios of combination are possible too. Even generator gas and blast furnace gas can be employed, especially if they are

corrected by the addition of hydrogen, naturally with the supposition that they are freed from contact poisons just as the water gas.

As catalysts we use, in contrast to Sabatier's synthesis of methane, generally not nickel, but cobalt or iron, and I should like to mention immediately at this place that we learned in the course of time to carry out the process also without activating admixtures of any kind; for example, with finely divided iron alone, or with finely divided cobalt alone. Naturally we profited by our experience which we gathered, working for years with similar catalysts.

An essential characteristic of our method is the use of temperatures that are too low for the formation of methane. The inertness of reaction produced thereby we balanced by the most careful preparation of the catalysts. And it may be interesting to know, that, while formerly we had to regenerate the contacts from time to time, today we know the conditions under which they become better and better by themselves.

The temperatures may be changed, depending in each case on the nature of the catalyst; but must always be so chosen as to stay below the temperature that is advantageous for the formation of methane in case of the catalyst in question. And it may be said that, in general, the temperature is the more favorable the lower it is chosen. The range of temperature in question lies between 200° and 300° C.

The products present in the reaction gas, namely, gasol, gasoline and vapors of petroleum and solid paraffin, we may imagine as having originated in different ways. If we imagine, for the sake of simplicity, first that 1 CO is reduced to the group CH_2, then the oxygen derived from the CO is met again in the form of water, or as carbon dioxide. Also the simultaneous appearance of water and carbonic acid is conceivable. In fact, the process can be arbitrarily so conducted that in addition to the higher hydrocarbons formed out of the CH_2 groups with simultaneous hydrogenation, either water or carbonic acid or both appear in the gas. It can be arranged thus, that after an eventual removal of the carbonic acid, the gas leaving the contact with reference to the part not yet converted possesses the desired relation of hydrogen to carbon monoxide.

Generally an approximate 50% yield can be attained with a single passage over a good contact, and then the choice presents it-

self either to pass the rest of the gas for a second time over the contact after the removal of the products of the reaction, insofar as they do not separate by themselves—for this purpose active charcoal or silica gel may be used, as is done today on a large scale in the American natural gasoline plants—or to use it in any other way, e. g., transform it into illuminating gas, etc. The quantitative ratio of the products of reaction mentioned, as we shall see, can be influenced. The simplest thing to do is to produce gasol, a mixture of ethane, propane and butane, that can be easily compressed and liquified. On another occasion we shall say something about its use.

While, as has already been mentioned, it is relatively easy to suppress the appearance of methane and to produce gasol in its stead, it required much more work and time to find the conditions under which instead of gasol, higher homologues, namely, the gasoline hydrocarbons, appeared in a good yield. Matters are complicated considerably by the fact that not only the different contacts, e. g., cobalt contacts and iron contacts, behave differently in themselves, but also the admixtures that are used for the enlargement and maintenance of the surface often blot out the conformity to law that one believes himself to have found.

It is relatively easier to achieve the synthesis of solid paraffin than to perform that of gasoline. For this we could profit by the experience that we had several years ago in the domain of synthol, and that again proved true here. In case of the presence of strong bases the polymerization continues until solid paraffin is reached. Therefore the impression is formed that polymerization, once begun, tries to go on at once to the end, and that certain difficulties present themselves to stop it just at hydrocarbons of molecules with medium size, e. g., gasoline. We can only be of the opinion already expressed by other parties in the field of catalysts that everything must be tried out, since nobody is ever safe from surprises.

If we compare our process with other gas catalyses, no astonishment need arise concerning the greater difficulty; but at the same time, we may wonder at the great variety of possibilities. If we take, for example, the synthesis of ammonia, there either arises or does not arise ammonia, as far as is known today, out of nitrogen and hydrogen. The only other variant is the magnitude of the yield. The same fact holds true for the formation of contact sulphuric

acid. Here, too, only a single reaction comes into consideration. In case of our synthesis the complexity of organic chemistry shows itself, as far as it can be considered here. We must and can prefer the origin of definite kinds of molecules, and I am convinced that we have, by no means, yet found the best conditions. We see this clearly from the progress that we have made only this year. Many hundreds of experiments, of which each lasted at least several days while others extended over many weeks and months, were performed by us in about twenty small contact furnaces, in the first instance, merely like laboratory experiments. The samples of pocket-size that I can show you here come from a small experimental plant in which we tested the best conditions on a larger scale.

These samples show you, for one thing, how the raw materials looked, for the contents of these three bottles are in the original state. The clear oil in the first bottle is the petroleum fraction which separated by itself in the condenser of the apparatus. The second bottle contains all high-boiling parts that leave the contact tube with a small quantity of lubricating oil and a more abundant quantity of solid paraffin, of which one part, as you can readily see, has already settled. Another part is still in solution. The contents of the third bottle have simply been driven off with steam, according to the usual method, from activated charcoal that served for the absorption of the gaseous gasoline. You see it is clear as water and in quality it corresponds to the so-called best gasoline de luxe. Naturally we tested it as a motor fuel, and it is not astonishing that it shows up well, considering its character and its great volatility.

I said in the beginning of my lecture that I would speak about our synthesis in the limits of the whole problem of the liquefaction of coal. Coming to the end, I hope that I have shown that the chemistry today has evolved to the point, that not only the raw materials are known, the bituminous coal or the carbon-monoxide, and the processes have been developed for liquefaction, namely, the high pressure hydrogenation and the catalysis at normal pressure, but also the different kinds of petroleum hydrocarbons such as cyclic or aliphatic, as may be desired, can be produced.

We have not yet a world oil famine, but when it comes, there will be available methods for overcoming it by means of the newer chemistry of coal.

As to the absolute yield, more than 100 g. of solid, liquid and easily liquefiable hydrocarbons to each cubic meter of water gas can be obtained if the gas is conducted several times over the contact.

Although we may assume that in the course of time the conditions may be worked out still better, it is, perhaps, most practical at the beginning to make the process an intermediate process in water gas plants, to take out the gasoline, and to continue to use the gas then left as formerly. Then only that water gas is to be considered as used for the gasoline which really disappeared at this time, and in this manner we arrive at the most favorable calculation, since then one has, to a certain degree, a theoretical yield. Moreover, there exists the possibility of approaching the theoretical yield of 180 g. per cubic meter by reconverting the hydrocarbons as methane and gasol that originated, perhaps without being desired during the process, by heat treatment, or, as the case may be, by addition of steam or carbon dioxide, into water gas, and conducting it once more over the contact.

Of course, for economic reasons, the most valuable coke will not be used for this purpose, but the grades of coal and coke that are the cheapest and out of which the water gas can be produced at the lowest prices.

The largest gas producers which the industry has at its disposal are the blast furnaces, the waste gas of which is relatively pure, especially in regard to sulphur, and could be used, too, for the production of gasoline if hydrogen were added or if a part of its carbon monoxide were converted into hydrogen. Finally we may mention that, of course, also natural gas or methane of any other origin can be used for gasoline production according to our method, if they are first mixed with steam or CO_2 and then heated to such a degree that water gas is formed.

As to the theory of the process, it is beyond any doubt that the contacts used absorb carbon by formation of carbides. We imagine that carbides richer in carbon than Me_3C are temporarily formed and are split up into higher hydrocarbons by the hydrogen mixed with CO. If, however, pure hydrogen is conducted over mixtures of carbides first produced with carbon monoxide, scarcely anything but methane appears. Perhaps hydrogen in the absence

of carbon monoxide hydrogenizes these carbides too much. The reason why the metals of the iron group are especially suitable as catalysts may be that they combine the property of forming hydrides and carbides at rather low temperatures; but it may be too that the temperature condition for the formation and the decomposition of the carbides is especially favorable.

The formation of the above carbides rich in carbon is very probable indeed. But up to now such carbides in a pure state have not been isolated. Perhaps their instability is the cause and this instability is at the same time the preliminary condition for their activity as intermediary reaction agents.

Gentlemen, several years ago the opinion was expressed in many quarters that organic chemistry had almost run its course. I shall give no opinion on that, but it may be said that the chemistry of carbon monoxide proves that, at least in the field of methods, results of no small importance are still to be attained.

The periodical Fuel wrote recently: "Nothing is more surprising, in consideration of the enormous amount of work that has already been done in the field of carbon compounds, than that there was yet so much to be discovered about such a simple compound as carbon monoxide."

ENGLISH DEVELOPMENT IN CARBONIZATION OF COAL IN GAS WORKS

By G. M. Gill

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Author's Note—Short tons of 2,000 lbs. and American gallons—83.3% of Imperial gallons—have been used throughout this paper. English costs have been calculated in dollars and cents at the rate of $4.86 per £ Sterling. N. B.—1 Therm equals 100,000 British Thermal Units.

When the author received an invitation to come and address you at this Conference it took him some time to decide upon the best subject to discuss, and while in the main he had to deal with conditions in England he yet had to limit his remarks to matters which were likely to be of more interest to those working in the United States.

He is not altogether ignorant of your conditions as he has previously made three visits to your interesting country, and those visits were entirely devoted to investigations of the methods employed in the American gas works and coke works.

People outside the gas industry are sometimes prone to think that gas has had its day, and that electricity will take its place. There are no signs of any such transformation, and in fact where electricity has been most strenuously pushed there gas also is making very satisfactory progress. Both are essential services, and will continue to be so. Both have a great future ahead of them. That is the position as the author sees it both in Europe and in the United States.

The carbonization of coal is essential for a country's well being. By this method, and only by this method, can a large number of essential materials be produced, to name only a few—gas, coke, tar, with its innumerable and valuable constituents, ammonia, and sulphur.

If only for war purposes the carbonizing of coal is essential. This was undoubtedly one of the outstanding lessons of the war. No country, for its safety's sake, can afford to neglect the development of its coal resources in the direction of coal carbonization.

The carbonization process has so far not been found practicable

for the purpose of generating electricity, but this may come. In any case the demand for the products derived from the carbonization of coal is likely to increase at least as rapidly as the demand for gas, which in England is growing steadily as will be seen from the following figures, relating solely to authorized gas undertakings. These are taken from the latest annual Board of Trade Returns for Great Britain:

TABLE I

Year	Total Gas Sold Millions cu. ft.	Total Number of Consumers	Length of Mains Miles
1921	229,077	7,560,310	39,547
1925	265,757	8,200,455	43,178
Equal to Increase of	16.0%	8.5%	9.2%

These figures show satisfactory progress, and are certainly considerably greater than the increase in the population during the same period. During the same period there has been little or no change in the calorific value of gas sold, and therefore the comparison is a fair one.

Other figures relating to the same years are as follows:

TABLE II

RETURN RELATING TO ALL AUTHORIZED GAS UNDERTAKINGS IN GREAT BRITAIN

YEAR	1921	1925
Coal carbonized—thousands of tons	17,650	19,080
Coke for Water Gas—thousands of tons	1,403	1,291
Oil for Water Gas— " " gallons	62,100	73,600
Coal Gas made—Millions of cubic feet	194,518	231,347
Water " " — " " " "	49,894	48,173
Other " " — " " " "	4,606	4,297
Total " " — " " " "	249,019	283,818
Coke and Breeze made—thousands of tons	11,630	12,770
Tar made—thousands of gallons	192,300	232,750
Sulphate of Ammonia—tons	130,000	141,000

TABLE III

From these it is seen that a good improvement is shown in the gas and tar made per ton of coal

	Per Ton of Coal Carbonized Gas cu. ft. per lb. Coal	Tar Gallons per ton Coal
1921	5.50	12.15
1925	6.02	13.45

These increases are undoubtedly due to the growth in the use of steaming in continuous vertical retorts, which development is discussed later in the paper.

It will be noticed that the percentage of water gas to the total gas made was 20.0% in 1921 and 17.0% in 1925.

Water gas is chiefly employed as an emergency gas—and how useful it has been during the present coal strike—to deal with sudden demands caused by cold weather and fog and excessive stocks of coke.

Most gas engineers do not consider their gas making plant complete unless they have a water gas plant of proportionately large capacity and a good supply of oil for all such emergencies, not the least of which are the serious coal strikes with which industry in England is cursed.

The Raw Materials of the Future

The quantity of products made during the process of gas making can be varied at will by the gas companies, which will use coal carbonizing plant or carburetted water gas plant largely in accordance with the demand and the revenue to be produced from the sale of by-products from the coal.

So far as the author can visualize the future it seems certain that there will be a great growth in the quantity of coal carbonized to take the place of the failing natural gas supply, and in order to reduce the quantity of oil used for gas making. Both factors will affect the United States, while the latter will exert its influence in Europe. The uses for oil are expanding so rapidly that the price is likely to rise above that at which it would pay to gasify it.

In an interesting and far-sighted paper by Mr. H. L. Doherty on "Raw Materials of the Future," read before the American Gas Association in 1925, he states that "it must be obvious to everybody, that, regardless of the price of oil, we cannot expect to compete with oil if we must use oil as our raw material, and yet our customer can use it as a finished fuel instead of gas."

Mr. Doherty is undoubtedly right, and it makes it clear that in

the future we shall have to rely more and more upon coal and solid fuels for gas making.

INCREASING USE OF COAL FOR GAS MAKING

Everything therefore points to the increasing use of coal for gas making, and the larger the demand for coke, tar, and ammonia products, the greater will be the quantity of coal used for this purpose.

How shall we carbonize the coal so as best to suit the conditions of the future? To answer this question we must know what those conditions will be.

Mr. H. L. Doherty in the paper previously referred to says, "What we need to best serve the public is the complete and universal abolition of all candle power and B.t.u. standards that are general in character, and each company should be allowed to select the B.t.u. standards it needs and to vary this from time to time provided customers are not subjected to expense or inconvenience."

FREEDOM TO CHOOSE THE HEATING VALUE OF THE GAS

Now those are the conditions existing in England in all those cities where the gas undertaking has put the Gas Regulation Act of 1920 in force. Under this Act 608 gas undertakings, mostly large, are operating, and the calorific value of the gas supplied varies from 560 to 270 B.t.u. per cu. ft. with an approximate average of 472.

An analysis of the Returns of the Board of Trade to the end of 1925 discloses the following figures:

TABLE IV

Number of Gas Undertakings	Declared Calorific Value B.t.u. (gross) per cu. ft.
4	250 to 375
84	400 " 440
141	450
56	460 " 470
63	475
44	480 " 490
186	500
30	510 " 600
Total... 608	Approx. Av.... 472

Lower standards than those in England have been generally adopted in many other countries, notably France, Italy, Germany, Belgium, and Canada.

The Gas Regulation Act, with the freedom it gives the gas supplier, has worked admirably, and without complaint from the public, if we except the initial stages when the public did not understand it. The selling of the gas by the therm (100,000 British thermal units), as provided for in this Act, is recognized in England as being a better method than the old one of selling it by the thousand cubic feet. A therm of gas is something definite, but 1,000 cubic feet may be anything.

The author agrees entirely with Mr. Doherty's views on the question of the freedom which should be given the gas companies to supply the grade of gas best suited to the local conditions. In his opinion it undoubtedly operates to the advantage of the public.

In the same paper Mr. Doherty states that "Except where we are primarily trying to make a high grade coke we should aim at complete gasification of coal and use, as far as possible, not the high grade coals but the inferior coals."

Here we have two entirely different conditions. The gas company wishing to make a high grade coke would want to supply a gas of high calorific power, and the company wishing to take advantage of the purchase of local inferior coals would want to supply a gas of low calorific power. The calorific standard of the former might be 550 and the latter 350, and such variation might be in the best interests of the public. Under present conditions in the greater part of the United States the latter company would be forced to adopt a more extravagant means of making the gas, but in England it would have the necessary freedom to do as it wished.

As a general axiom it can be laid down that with freight costs high per ton, it pays to use a high quality coal and with freight costs low per ton, it pays better to use a cheap coal. The conditions are therefore entirely different between one undertaking and another, and it is for this reason that strong arguments can be put forward for freedom of choice in the matter of calorific value of gas.

In choosing the most suitable carbonizing plant for any particular conditions it is often found that the whole question largely hinges upon the type of coke which it is desired to make. If metallurgical, the adoption of ovens is, of course, essential; but if it is

desired to supply the domestic demand the choice of plant can be thrown open to large or small ovens, continuous or intermittent vertical or horizontal retorts, and to the author's mind, this applies equally to both the United States and England.

In England the choice almost invariably lies between continuous vertical or horizontal retorts. Ovens as yet find no place in English gas works, and practically all metallurgical and foundry coke is being made in coke oven works which have no connection whatever with the gas industry. The author believes this to be a mistake, as there is undoubtedly every reason for the coke and gas making industries to work together, and in this respect the United States has set a notable example.

To deal now with the chief types of carbonizing plant used in England:

The Pre-War Developments in Carbonizing Plant

At the beginning of the present century the choice lay between horizontal and inclined retorts, with gradually improving producers and recuperators. In those days the stoking machines were only capable of charging and drawing 10 feet of horizontal retort, and this meant that machines with coal handling and storing plant and with hot coke handling plant had to be installed on each side of "through" horizontal retorts, thus involving a large capital outlay and a high labor cost in operating.

As a consequence, inclined retorts with machinery limited to coal handling on one side and hot coke handling on the other were considered by many to be superior to machine-operated horizontal retorts.

Had developments with horizontals stood still, inclined retorts would undoubtedly have been improved still further and might eventually have ousted horizontal retorts; but three important developments took place in regard to working the latter type, and these effectually gave the death blow to the inclined type.

Firstly, machines were developed to discharge through horizontal retorts by pushing instead of drawing the coke, thus enabling one machine on the one side and one man to do the work formerly done by two machines and two men, and what was more important it enabled the horizontal retorts to be heavily charged with coal, as

the new type of machine did not require any free space over the charge for its operation as did the drawing machines.

It was soon found that the heavy charge had many advantages over the light charge. It lessened the effect of the hot radiating surface of the retort on the gas and liquid products, and it used the heating surface of the retort to greater advantage, thereby resulting in an increased quantity of coal carbonized from a given plant and quantity of fuel. As a consequence, better all round results were obtained and another important step forward was made.

Simultaneously, important developments were taking place in the stoking machines. The De Brouwer machine was invented whereby a charge of coal of any desired weight could be thrown in by centrifugal force from one end of the retort. The Fiddes-Aldridge machine for simultaneously discharging and charging the retort in one operation was introduced, and by its excellent design and reliable working quickly made a name for itself, but it did not enable the full advantage to be taken of the heavy charge, as in this direction its capacity was limited. Of recent years this drawback has been removed and it can now effectually deal with heavy charges of coal.

These developments sounded the death knell of the inclined retort, and from this time, 1906-1912, keen competition arose between the horizontal retort systems and the newly developed continuous vertical retorts.

English Gas Coals

It is very difficult to give any clear idea of the coals used in English gas works. These vary to such an extent as to render any short description distinctly misleading.

Gas coal is produced by collieries in Durham and Northumberland, Yorkshire, Lancashire, Nottingham, Derbyshire, Warwickshire, Leicestershire, Staffordshire, Somersetshire, and in Scotland.

The Durham coals are extensively used by those gas works able to take delivery of seaborne coal, notably in London. The coal is of a strongly swelling and caking type, contains considerable "fines" and needs more heating to carbonize it than is the case with other English gas coals.

Many of the Yorkshire coals are of excellent quality and easy to carbonize. The coal—Mitchell Main Gas Nuts—tested by the Fuel

Research Board is fairly typical of such coals. The Durham and Yorkshire coal fields produce the greater part of the English gas coals.

The author gives below analyses of typical gas coals, though he considers that the figures should be taken with considerable reserve as merely giving an idea of the class of coals used in English gas works.

Table V

	Moisture	Vol. Matter	Fixed Carbon	Ash
Durham (various)	1.0–1.5	26–33	56–64	5–10
Yorkshire (Mitchell Main)	0.8–1.3	29.9–30.8	52–61	6.5–9.5
Lancashire (Arley Nuts)..	1.1–3.0	33–35	57–58	5.5–7.5
Derbyshire (Wasted Nuts).	6.5	32	53.5	8.0
South Wales (Meiros)	1.5–1.8	31.9–32.2	56.3–56.8	9.4–10.0
Scotch Lanarkshire (Main and Ell Wasted Nuts) ..	9.5–10.5	30.1–33.1	49.8–52.7	5.9–7.6

The survey of English coals, which is now being undertaken by the Fuel Research Board, will be very valuable, as it will supply information which at present is entirely unavailable.

Horizontal Retorts

In England there are three large and energetic firms, and several smaller firms, chiefly specializing in the horizontal retort system, and these firms have successfully kept this system very much alive.

The modern designs of horizontal retort settings for large works chiefly provide for 8 or 10 through retorts, mostly D-shaped and set in two vertical rows per setting. Their length varies from 20 to 23 feet from wall to wall, and in section they are mostly 24″x18″.

These sizes of retorts have been chosen more on account of their suitability for the various machines used for their charging and discharging, rather than for their suitability for carbonizing coal.

In the author's opinion the section commonly employed in the United States, namely 26″x16″ D-shaped, is superior, and his belief is that the comparatively shallow depth in proportion to its width is a factor of importance as influencing the rapidity with which a charge of coal can be carbonized.

It is usual in England to provide a large combustion chamber, as shown in Fig. 11 to localize the intense heat and prevent it from im-

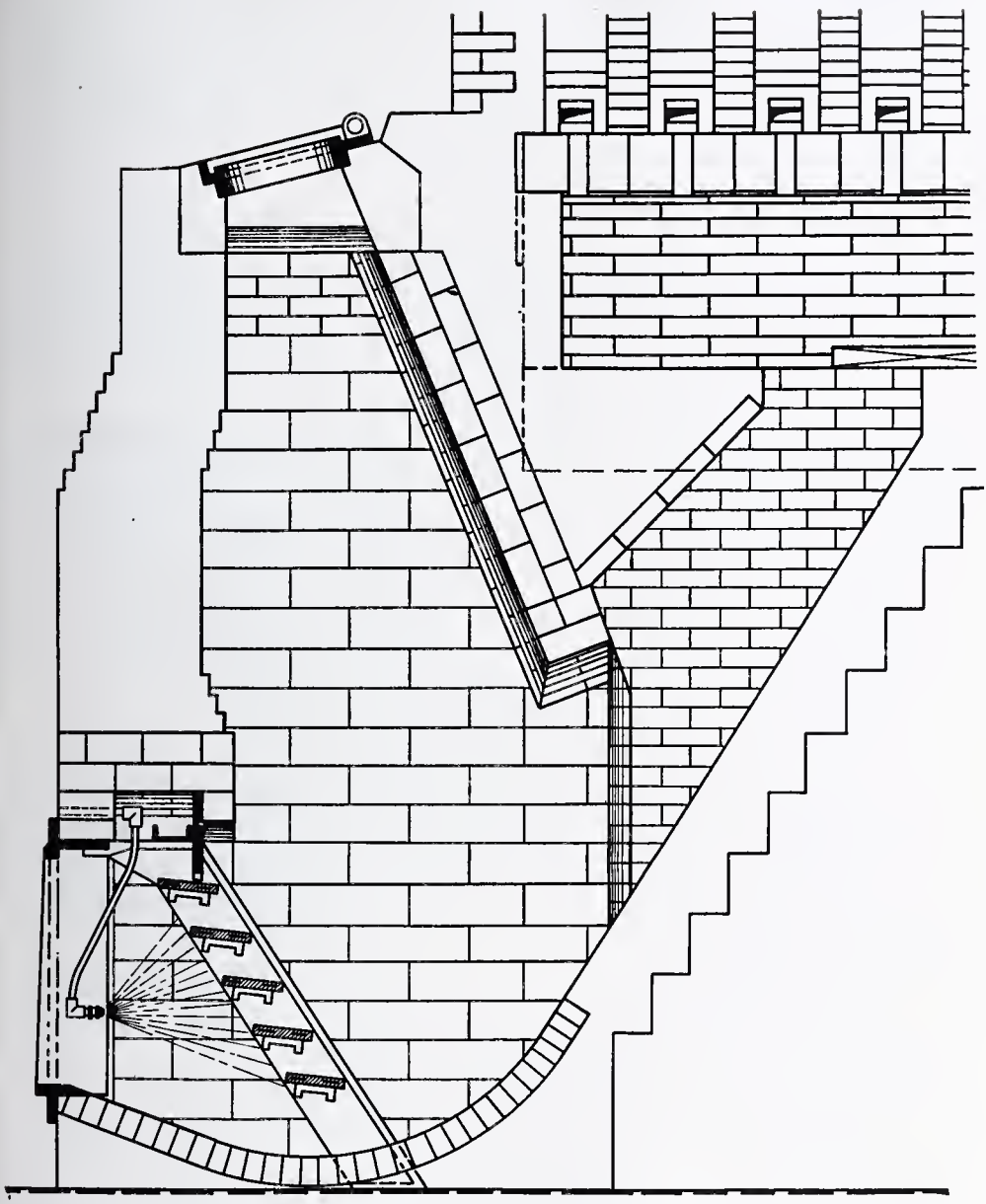


FIG. 1. TYPICAL PRODUCER AS USED IN ENGLISH GASWORKS
This shows the Gill atomised water spray in use for cooling the grate and providing steam.

pinging directly on any retort, and to provide facilities for men to enter and thoroughly repair holes which are more apt to develop in the vicinity of the combustion zone than in any other part of the setting.

Horizontal retorts set in 3 vertical rows per setting and in 3 horizontal tiers, as designed originally for hand work, are no longer built in new retort houses, largely on account of the fact that this design is wasteful of space.

It is usual to fit two ascension pipes of 6″ or 7″ dia. to each retort, largely for the reasons that they provide a more rapid and unrestricted outlet for the gas and liquid by-products, and that there is, thereby, less degradation due to radiated heat, while the formation of naphthalene and sulphur compounds is lessened.

The arches of the settings are frequently made barrel-shaped to increase their strength and to prevent the tendency to sag in the middle.

The recuperators are made of various designs, not unlike, and probably equally as efficient as those used in the United States.

There is a tendency to dispense with the recuperator altogether, and replace it with a waste heat boiler, wherever there is use for the steam.

PRODUCERS

It is usual to provide one producer per setting, this being built under the setting or in a position projecting some feet outside the front wall. In the latter case better facilities are thereby provided for filling the producer with hot coke, most of which can then drop directly through the charging opening.

Step grates are largely used, one of typical design being shown in Fig. 1, while an inreasing number are being fitted with bars sloping downwards, as shown in Fig. 10a.

A very good type of grate of this design is that shown in Fig. 12. In this case provision is made for placing the bars higher or lower, as may be desired by means of notches fitted in the bars, these engaging with a supporting bar similarly notched. By such means the space between the bottom of the bars and the bottom of the grate can be regulated.

In these latter types of grates all the clinker is drawn out under the bars, it only being necessary to cut it away should it form upon the

sides of the producer, and of then allowing it to find its way to the bottom of the grate.

These types of grates show much advantage over the flat bar type previously employed, and are now invariably used in modern works.

By their use it is possible to dispense almost entirely with false bars, or a false grate, while clinkering, and, in fact, no metal other than the clinkering tool need be handled.

During the War when the author was Chief Engineer of the South Metropolitan Gas Company of London, hundreds of these producers were clinkered for 2 or 3 years entirely by women, who also did all the other work in many of the retort houses of the company.

GRATE AREAS

The grate areas of producers have been substantially increased of recent years, and it has been found to be of considerable advantage in improving the quality and quantity of producer gas made, in saving

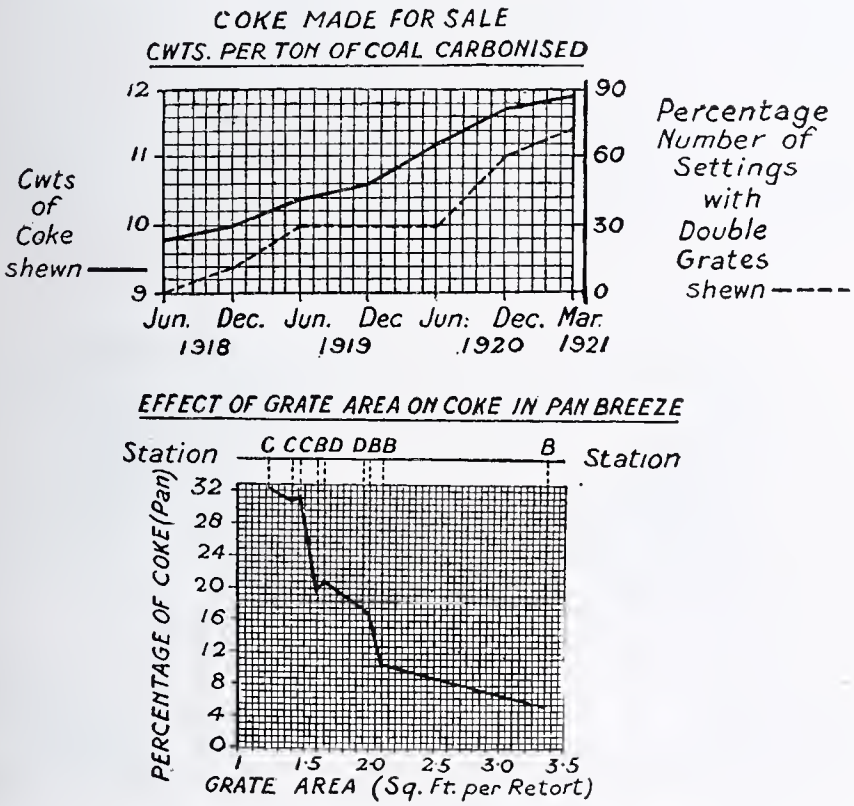


FIG. 2. SHOWS EFFECT OF LARGE GRATE AREAS

labor in clinkering, and in reducing the amount of combustible fuel in the ashes.

In this respect 2.0 to 2.5 sq. ft. of grate area per 20 feet of retort is a good figure at which to aim.

Some results of a long series of experiments with different grate areas are shown in Fig. 2. In explanation of Fig. 2 it was found that the percentage of combustible matter in the furnace ashes or pan breeze from the retort settings varied very largely with the amount of grate area. The larger the grate area, the lower the combustible matter in the ashes, and vice versa.

This is shown in the lower diagram of Fig. 2. In the upper diagram the saving in fuel by increasing the grate area is reflected in the larger quantity of coke made for sale per ton of coal carbonized, and this increased pro rata with the number of producers converted. The marked improvement was largely due to the better quality and more uniform quantity of producer gas made and not only to the saving of loss in the ashes. The better and more uniform heating of the retorts resulted in a larger throughput of coal.

The grate areas of most of the producers in the works of the South Metropolitan Gas Company were doubled a few years ago with great advantage, and it was found that it was possible to burn successfully bad coke, which, with a small grate area, would have been very troublesome.

An example of these enlarged grate areas is shown in Fig. 3.

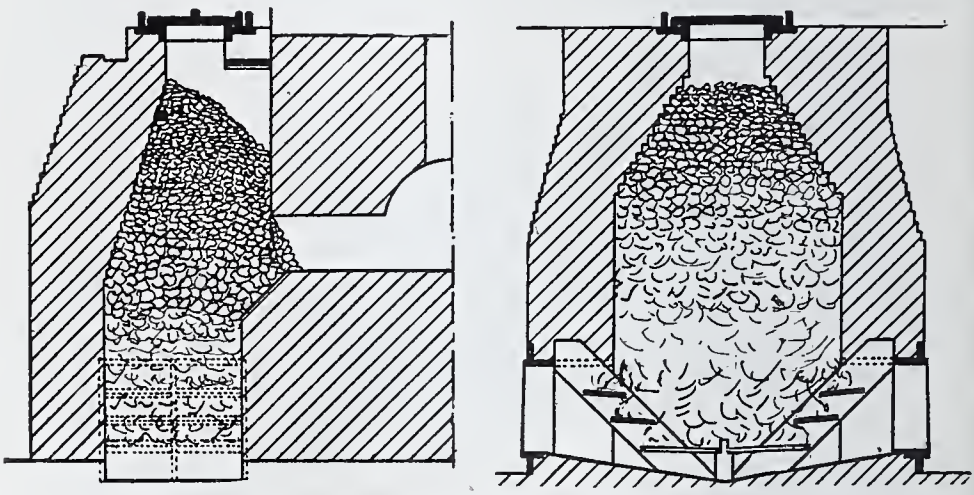


Fig. 3. Producers With Basket Type of Grate

Steam was frequently employed for the producers, but so far no progress has been made in England with the return of waste gases to the bottom of the producer.

The author has, in conjunction with Messrs. Gibbons Bros. of Dudley, introduced with satisfactory results the use of atomizers for spraying a mist of water upon the types of grates above described, as shown in Fig. 1. This is equally as effective, but much cheaper than steam.

When using 0.6 lbs. water in these atomizers per 1.0 lb. of coke burnt, this quantity is sufficient to keep the bars cool and ashpit dry—the latter condition being, in the author's view, distinctly advantageous.

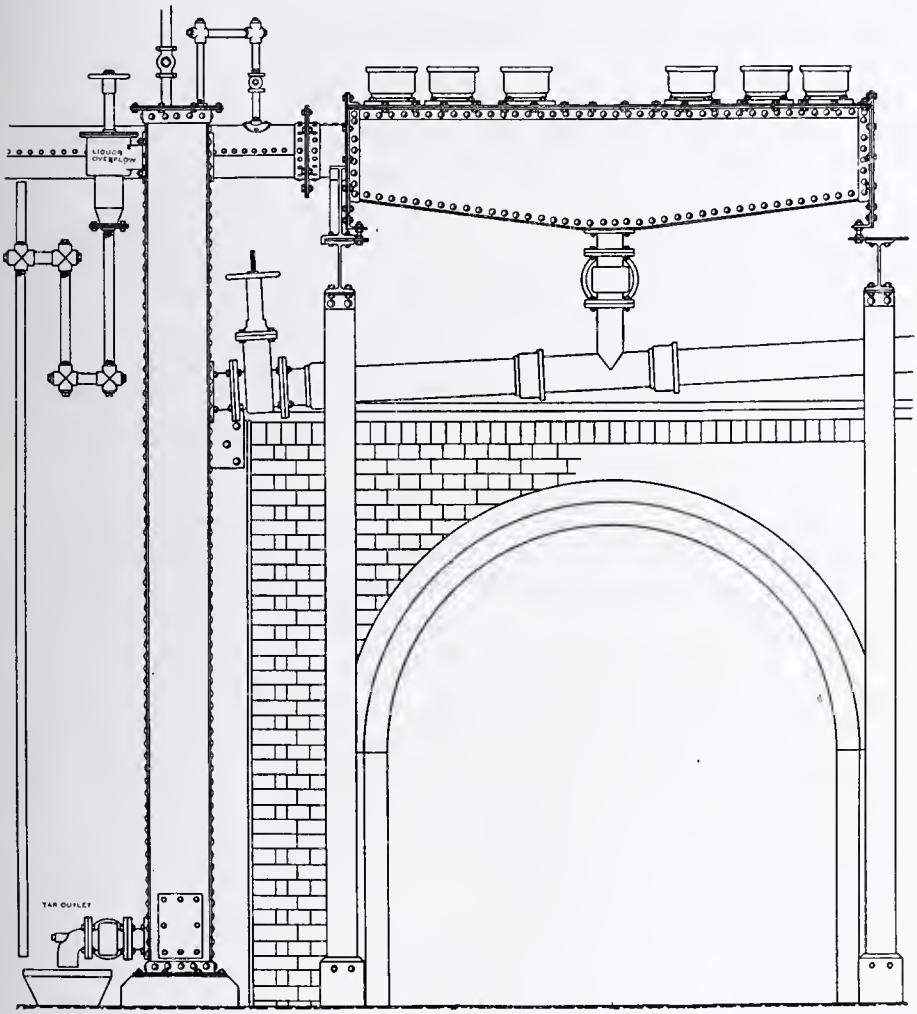


FIG. 4. TAR TOWER

and in this way the resulting ashes are dry and can be, if desired, more effectually separated, the clinker from the coke, thus providing a dry fuel.

Producers with Open Doors

Many producers are now working with open doors, and, it is considered, with some advantage; but in these cases it is necessary to fit an outlet damper to the producer.

The object of the open producer door is:

1. To maintain a steady and continuous supply of producer gas, as by this means the amount of air drawn into the producer is not varied to any extent, even when cleaning the fire. With closed doors too much air is drawn through the producer whenever the doors are opened for cleaning the fire, resulting in some waste of fuel.
2. To enable a slight pressure of gas to be maintained in the top of the producer, and so prevent the admision of air into the charging opening.

With good producers properly worked it is possible to maintain a uniform supply of producer gas containing an average of 25% or over of CO.

The author has devoted a good deal of space to the question of producers, as he is convinced that their design and operation have a very important bearing upon the results from the entire plant.

Removal of Tar from Retort Settings

The usual arrangement employed in England consists of a tar tower, shown in Fig. 4, connected by a tar pipe to the hydraulic mains of several settings of retorts.

The tar as formed immediately flows to the outlet and finds its way down the tar main into the tar tower, and by so doing it displaces an equal volume of liquor in the tar tower, causing this liquor to flow in the reverse direction to the tar through the tar main into the hydraulic main. The level of liquor in the hydraulic main is maintained constant by the level of the liquor in the tar tower, in which an adjustable overflow pipe is fitted.

Several hydraulic mains, and preferably not more than five, may be connected to one tower. Should more than this number be so connected it is found in practice that the friction in the tar main over so great a distance is such that the tar and liquor will not read-

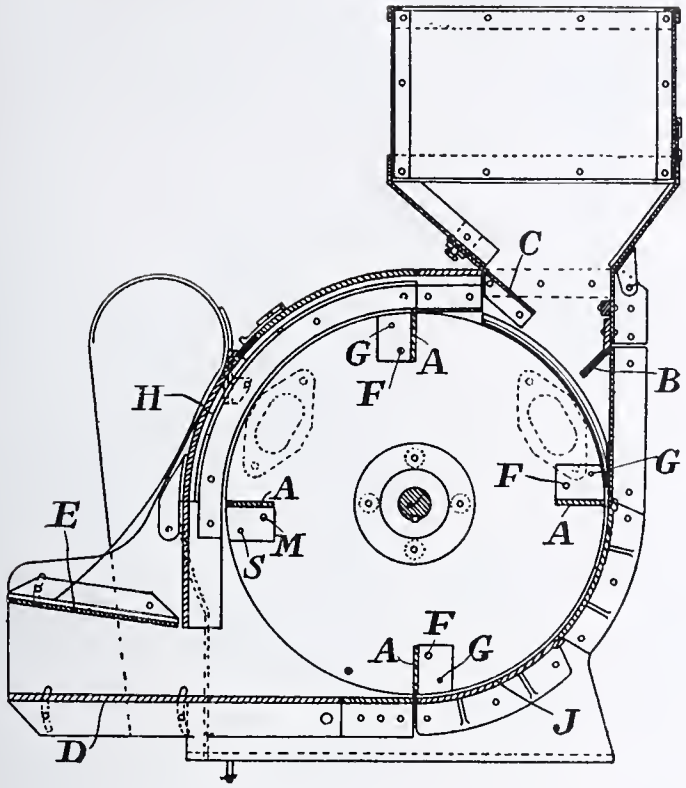


Fig. 5. The Drake Projector

The side discs of the projection, which is mounted on a driving shaft, carry blades A fixed near their peripheries. A baffle B deflects the coal and directs it between the central driving shaft and the inner edges of the projector blades A. An adjustable sliding shutter C, actuated by a handle, is arranged to limit the size of the passage leading from the coal shoot to the baffle B, by which means the charge may be controlled.

The base plate D and the roof plate E at the outer orifice are pivotally mounted for control of the trajectory of the projected coal; while the keeping of the blades A to a smaller depth than that of the outlet orifice ensures that the air propelled is not of sufficient volume to cause any undesirable raising of dust, projecting of flames, etc.

To provide against serious jamming and breakage, the blades A are fixed to the discs by pivotal pins F and weak bolts G; so that in the event of obstruction the bolts G would shear, and allow the blades to swing on the pins F.

H is a hinged door which allows interior repairs to be easily effected; and J is a removable part of the casing which permits of substitution of this part subjected to heavy wear.

ily flow in opposite directions in the same pipe. It is therefore advisable to limit the overall length of the tar main to about 55 feet.

The hydraulic mains are connected by means of an equilibrium pipe to the tar tower to which they are attached, the object of this arrangement being to equalize the level of the liquor both in the hydraulic mains and the tar tower.

English Stoking Machines

Of the modern stoking machines there are four which are largely used. The De Brouwer Charger and Discharger and Drake's Charger and Discharger both comprise a separate machine for charging and discharging, though both machines are frequently fitted to the same framework and carriage. The other two machines, the Fiddes-Aldridge and the Guest-Gibbons, are in each case machines in which both the charging and discharging mechanism is combined in the one apparatus. The first discharges the coke while charging the coal during the same outward stroke. The second machine discharges the coke, and then returns to its original position and proceeds to charge the coal in three separate strokes.

All these machines are capable of putting heavy charges into the retorts with a great variety of coals, and of discharging the coke with speed and certainty. To deal with each machine in more detail:

De Brouwer Machine

This type, with charger and discharger, is as well known in the United States as in England and will therefore not be described.

Drake's Projector

This machine consists of a rotor similar in construction to the paddle-wheel of a steamer. The coal is fed in a controlled stream from a hopper above into the rotor, where it is picked up by the blades, of which there are four in the rotor, and thrown by centrifugal force into the retort.

The rotor is divided vertically into two parts, and deals with the coal in two separate streams.

A view of its internal construction is given in Fig. 5.

A large number of these machines are working successfully in

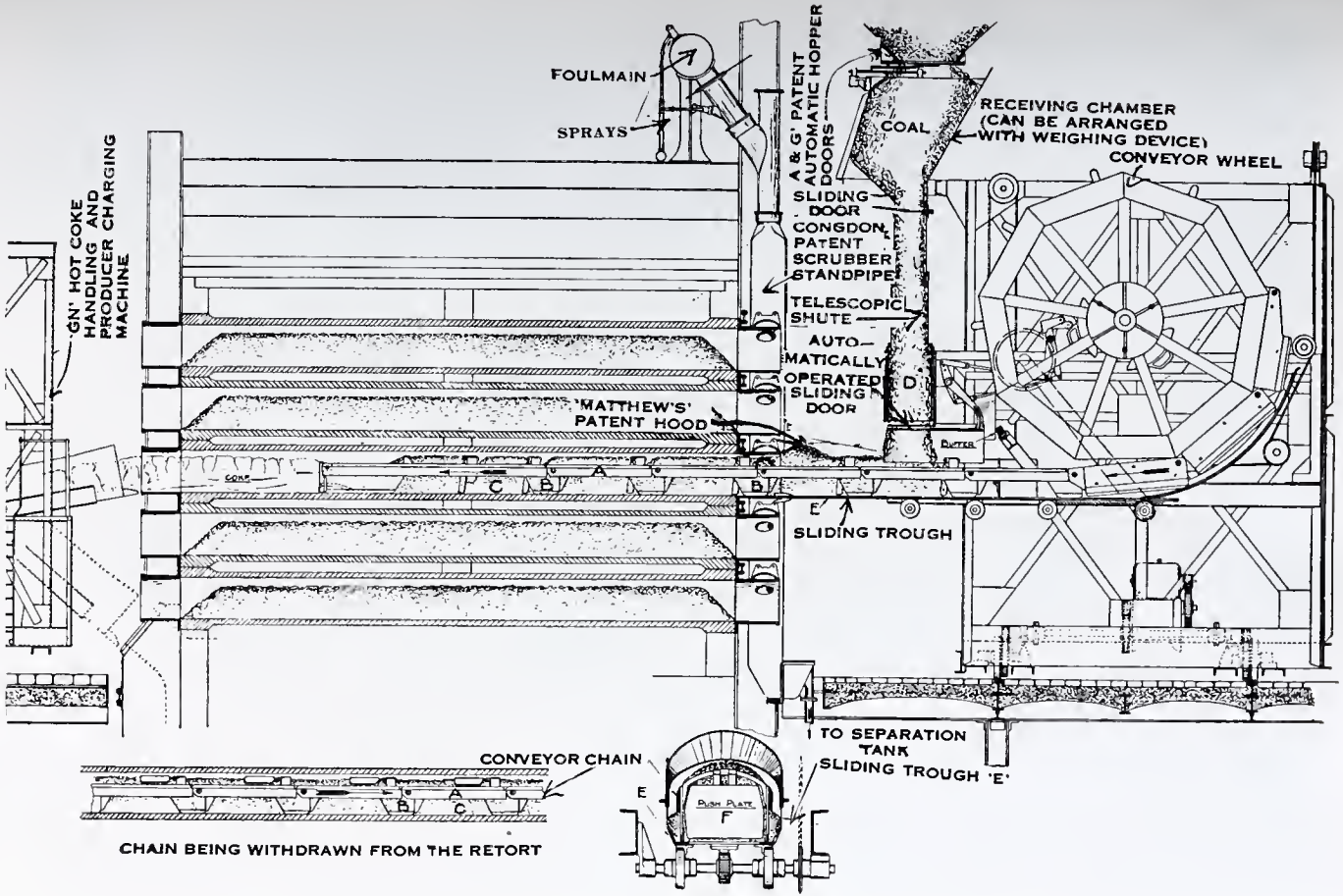


FIG. 6. THE FIDDES-ALDRIDGE (F-A) IMPROVED SIMULTANEOUS RETORT CHARGING MACHINE. OPEN-SIDED TYPE.

England, and they have proved their ability to charge retorts with speed and uniform quantities of coal of all kinds.

Fiddes-Aldridge Simultaneous Discharger and Charger

A number of these machines are at work in the United States, and a very large number are operating in England. The machine consists of a special push plate conveyor, which, when propelled into the retort, pushes the hot coke in front of it while taking a full charge of coal at the same stroke.

The coal is supported in the outward stroke by a series of hinged push plates fitted a few feet apart, and by the side plates, the whole substantially the same height as the charge of coal.

When the conveyor reaches the end of the retort and the coke has been discharged the conveyor is withdrawn, this causing the push plates to take up a horizontal position immediately above the coal and to be drawn out without hindrance.

The side plates of the conveyor are drawn through the coal.

At one time a disability of the machine was that it was unable to place large charges of coal into the retort, but this fault has now been corrected by a modification in which a considerable number of large openings are cut out in the side plates throughout their length, thus permitting a larger feed of coal per foot of retort, this excess flowing freely through these openings during its outward stroke. The larger charge is facilitated by the use of Matthews' Hood shown in the illustration, Fig. 6.

A heavy charge in England is frequently specified as a charge of coal which will fill two-thirds of the full cubic area of a new retort, the remaining one-third allowing for carbon growth, expansion of the charge, irregularities of the retort itself during its life, and gas space.

The makers of the F-A Machine with the modifications briefly described and shown in Fig. 6, state that this size of charge can be guaranteed.

The Guest-Gibbons Charger-Discharger

This machine (Fig. 7) is not well known in the United States, but it is being widely adopted in England, particularly in the

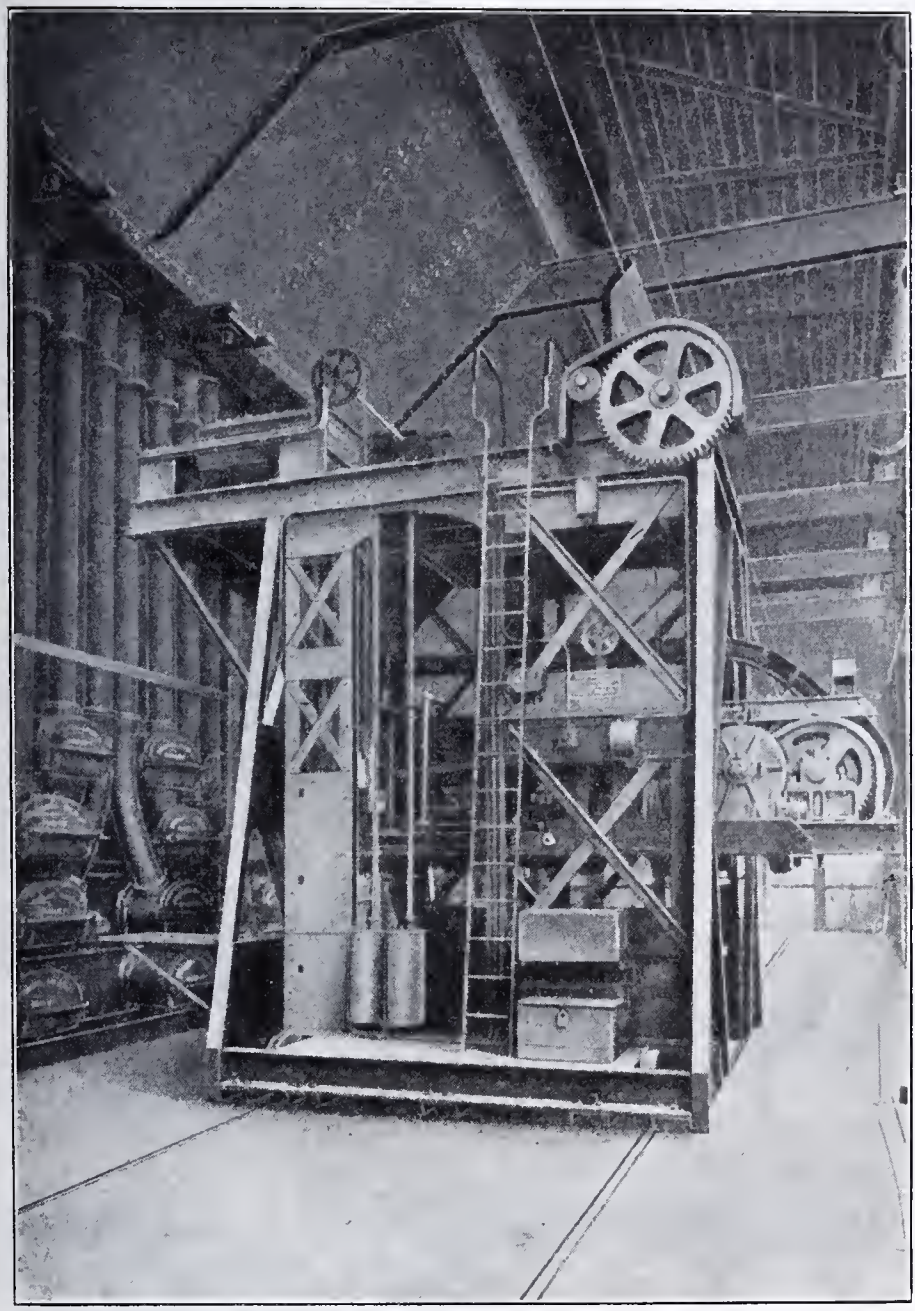


FIG. 7. THE GUEST-GIBBONS COMBINED CHARGER AND DISCHARGER

medium and small horizontal retort houses of, say, 100 retorts and less, and as a standby in the larger retort houses.

This machine contains the whole apparatus for discharging and charging in the one beam, and is therefore to this extent like the F-A machine.

The operation of discharging and charging is as follows: the coke is first pushed out, the position being as shown in Fig. 8. The apparatus is then withdrawn from the retort, and the drag bar, or "coal carrier," comes to rest immediately under the coal feed. Having received a charge of coal it is pushed to the far end of the retort, the drag bar then being lifted vertically through the coal and withdrawn, the same operation being performed three times in all to charge a full length of through retort.

It is stated that it is capable of doing the entire operation of discharging and charging retorts in 2 minutes, this being the only reason that it is usually not adopted for large retort houses. On

Fig. 8. Position for Discharging Coke

Fig. 8a. Position for Taking in Coal

Fig. 8b. Position After Placing Charge of Coal

FIG. 8. THE WORKING MECHANISM OF THE GUEST-GIBBONS COMBINED CHARGER AND DISCHARGER

the other hand, it inserts the heaviest charges of coal lightly, by reason of the upward withdrawal of the drag bar through the charge, and in an even layer. It is reliable in working and solid in construction and is cheap to install.

Some sectional views of modern horizontal retort houses are shown in Figs. 9 and 10.

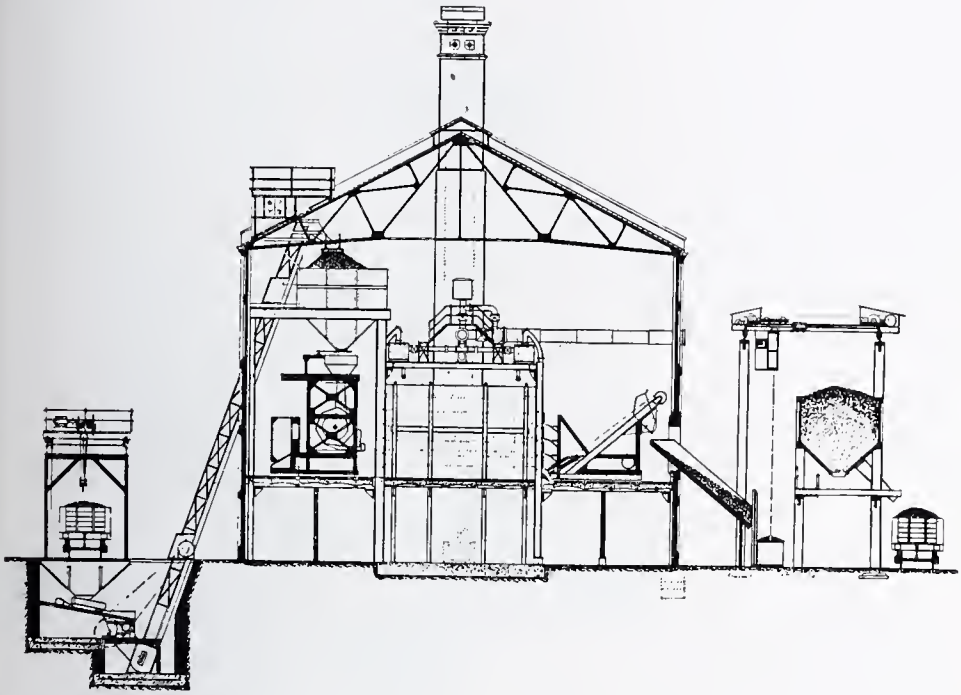


Fig. 9. Cross Section of Retort House Showing Coal and Coke Handling Plants at Lytham

In the case of Fig. 10 there are 14 settings of ten 24″x18″x23′ D retorts, half of which are of moulded fireclay and the other half of silica segmental blocks.

In this retort house a Drake's combined Charging and Discharging machine is used, and the coke is received in a G N Hot Coke Transporter, shown in Figs. 10 and 10a, which consists of a steel tube slightly larger than the retort section, either end of which may be elevated by means of wire ropes while the other end is at rest in a hinge or trunnion.

The tube is lined with steel rails and intermediate cast iron wearing blocks. When the outer end of the tube is in its lowest position it communicates by means of a tail plate with the outside quenching

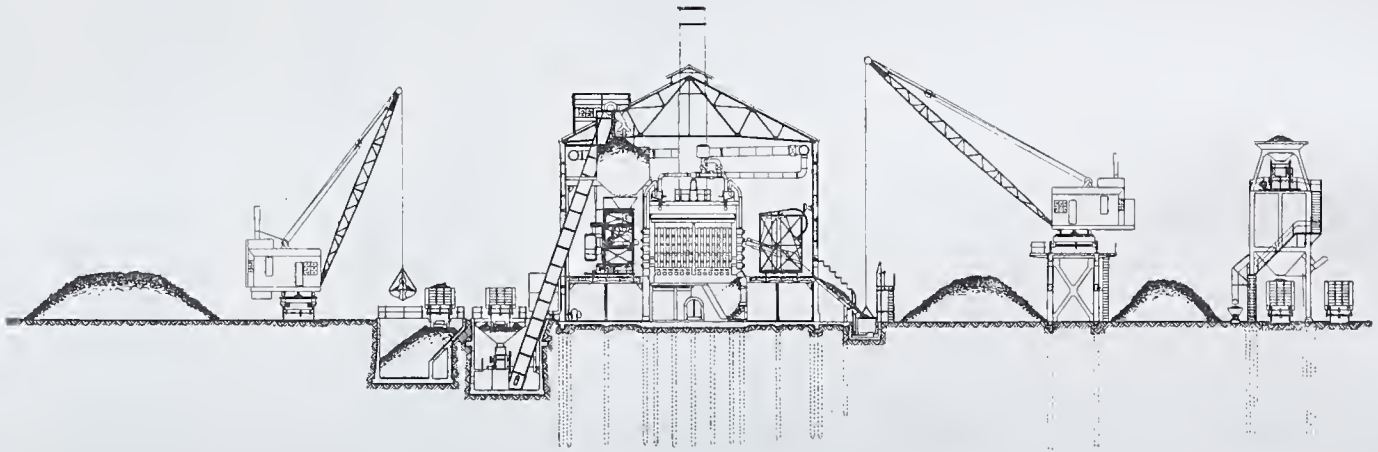


Fig. 10. Cross Section Showing Relation of the Coal Handling, Carbonizing and Coke Screening Plant at Swansea

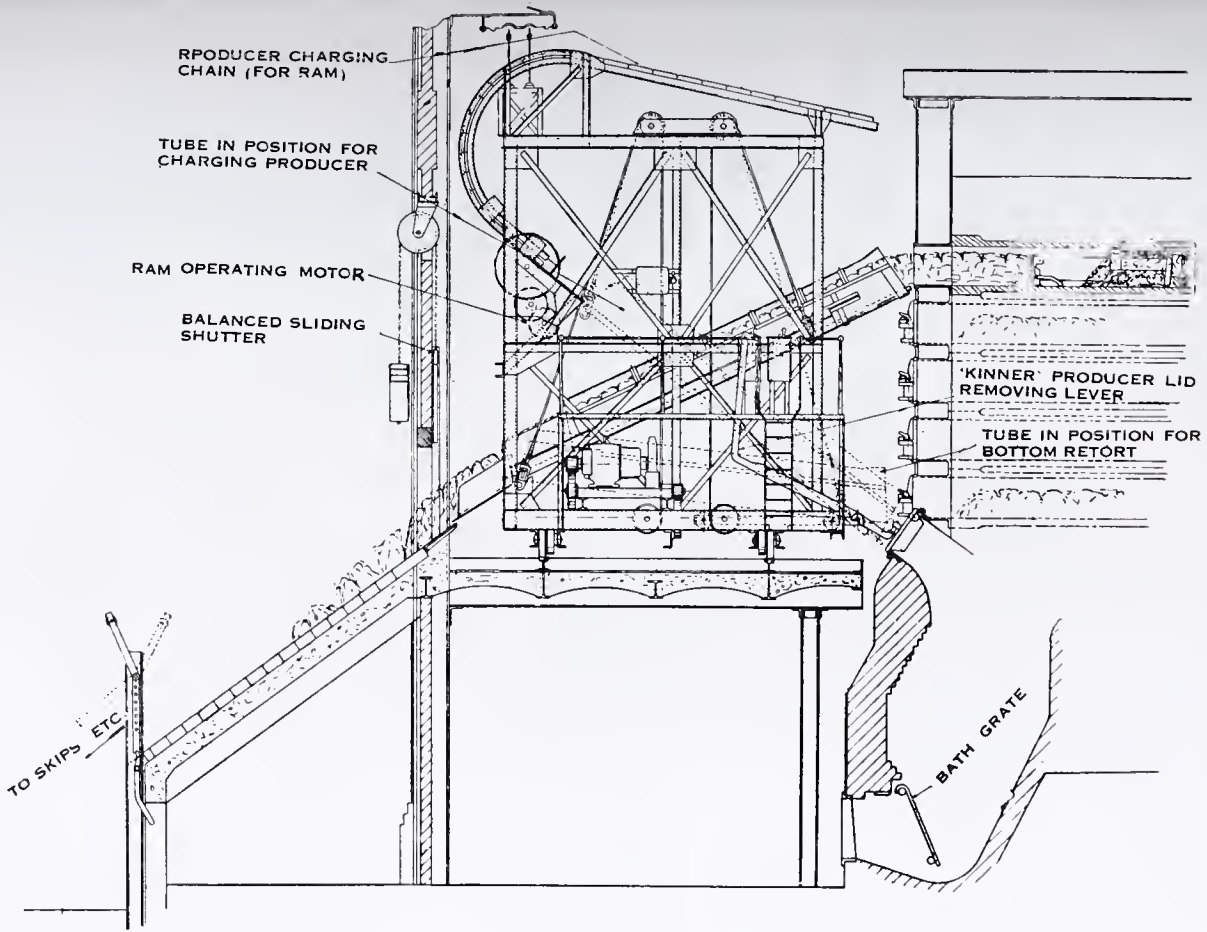

RPODUCER CHARGING CHAIN (FOR RAM)
TUBE IN POSITION FOR CHARGING PRODUCER
RAM OPERATING MOTOR
BALANCED SLIDING SHUTTER
'KINNER' PRODUCER LID REMOVING LEVER
TUBE IN POSITION FOR BOTTOM RETORT
TO SKIPS ETC
BATH GRATE

FIG. 10a. G. N. HOT COKE TRANSPORTER

bench, and the other end of the tube may be hoisted to any mouthpiece whence it receives hot coke through suitable guide shoots or nosepieces.

From the top and second tiers the charge slides directly on to the bench and to the bottom gates. From the lower retorts the coke remains in the tube until the latter is raised to a steeper incline, at which it will slide freely. The coke from the bottom retorts is usually fed to the producers.

For producer charging the machine is brought opposite the producer opening and the tube tipped in the opposite direction, the coke sliding by gravitation into the producer, or aided whenever necessary by a ram. A producer lid lifting lever is incorporated in the machine, and the lids can be lifted, moved clear and replaced by the operator from the platform.

Separate motor and control gear is provided for the travelling motion and for hoisting of the tube.

The quenching bench is constructed of reinforced concrete having short columns at the bottom, while at the top it is fixed to the retort house stanchions. The floor is covered by a 3″ course of special acid-resisting bricks, the bench sloping at an angle of 40 degrees to the horizontal.

At the bottom of the bench special gates are fixed which are automatically opened and closed by the coke skips.

The coke is removed from the quenching bench in 2.48 ton skips by a 6.7 ton crane which delivers the coke to coke screens prior to storage in overhead hoppers.

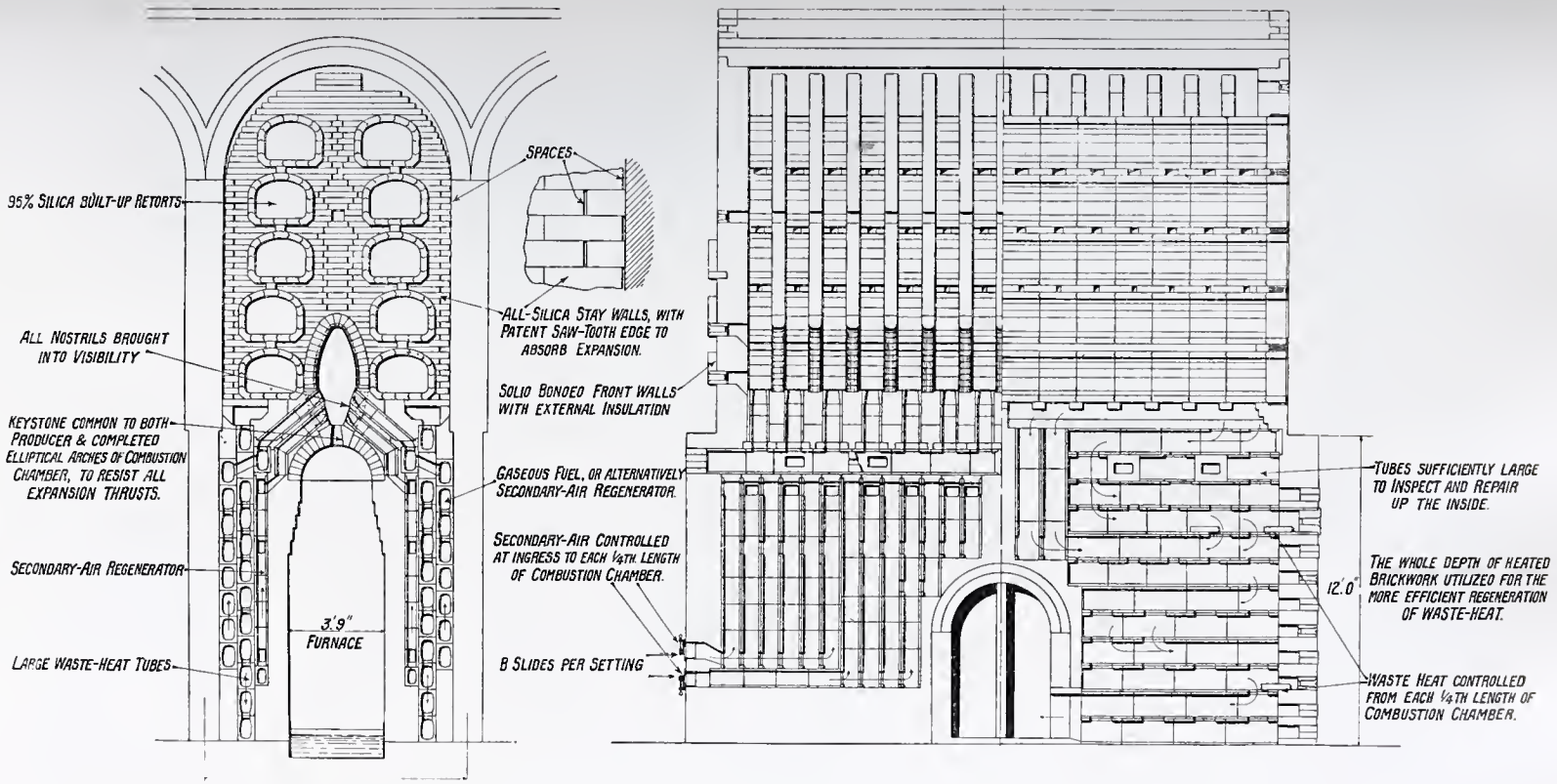
As is usual in English gasworks all the electric power required is generated on the works.

An interesting horizontal retort house was recently built by Mr. William Carr, engineer to the Stretford Gas Company.

The retort house contains 18 settings of 10 24″x18″x22′0″ D retorts in silica segmentals, these being fitted with a special recuperator of novel design and an improved type of scrubber standpipe.

The recuperator is shown in Fig. 11, its object being to provide facilities for firing the settings by external producer gas or by coal gas, or by a mixture of both, as an alternative to ordinary coke firing in its own internal producers.

It will be seen that there are 3 sets of flues in the recuperator, those


95% Silica built-up retorts
All Nostrils brought into visibility
Keystone common to both producer & completed elliptical arches of combustion chamber, to resist all expansion thrusts.
Secondary-air regenerator
Large waste-heat tubes
3'9" Furnace
Spaces
All-Silica Stay Walls, with patent saw-tooth edge to absorb expansion.
Solid Bonded Front Walls with external insulation
Gaseous fuel, or alternatively secondary-air regenerator.
Secondary-air controlled at ingress to each 1/8th length of combustion chamber.
8 slides per setting
Tubes sufficiently large to inspect and repair up the inside.
12'0"
The whole depth of heated brickwork utilized for the more efficient regeneration of waste-heat.
Waste heat controlled from each 1/8th length of combustion chamber.

Detail Elevation *Detail Section*

FIG. 11. REGENERATOR SETTINGS, STRETFORD GASWORKS

in the middle being for the waste gases, and when coke firing in the ordinary way the other two sets of flues are used for heating the secondary air; but when an external supply of gas is being employed the outer set of flues is used for preheating such heating gas, the change being made without any difficulty.

Normally at Stretford a fine slack coal from local collieries is used, and this coal produces a coke which sells at a price substantially higher per ton than the price of the coal.

Mr. Carr assumes that 35,700* cubic feet of 520 B.t.u. coal gas is equivalent for heating purposes to 1 ton of coke and he estimates their values at 12 cents (works cost) per 1,000 cu. ft. and $5.97 per ton, respectively.

Upon this basis, and assuming that the coke used in the furnaces is 250 lbs. per ton of coal, then—

Coke firing would cost 75 cents per ton of coal carbonized.

Coal gas firing would cost 54 cents per ton of coal carbonized.

The producer used for coke firing measures 3′9″ wide by 5′4″ back to front with a fuel depth of 7′0″.

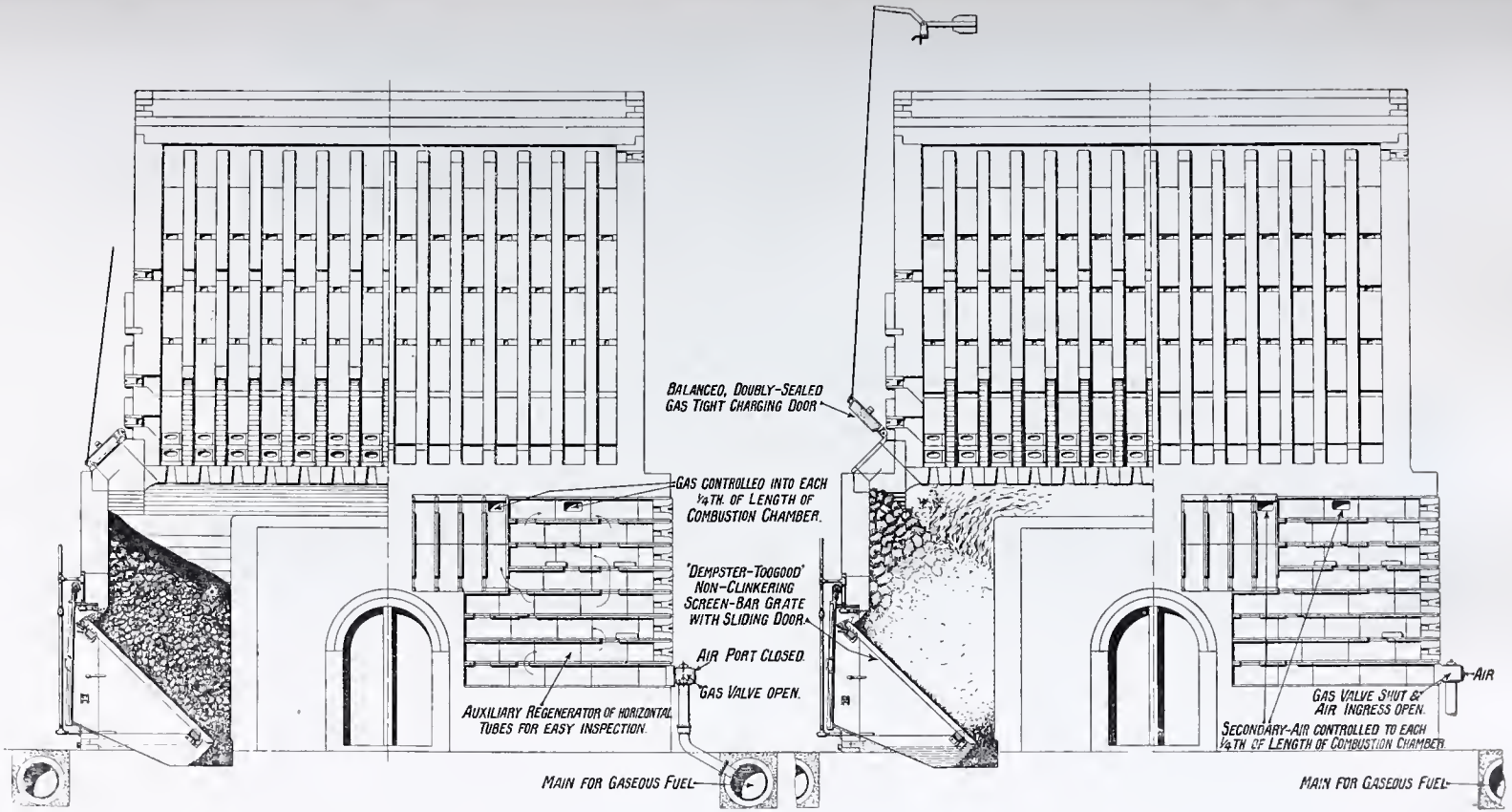
The grate consists of special bars arranged as shown in Fig. 12. The grate area is 26.25 sq. ft., or 2.39 sq. ft. per 20 ft. of retort, steam or water being used for cooling the bars, the ash pits being kept virtually dry.

These producers are undoubtedly very satisfactory and have a full share in the success of the installation.

The scrubber standpipes fitted to the retorts are claimed to be an improvement on the design generally used, and are shown in Figs. 13 and 14. It will be seen that these taper upwards and are of larger sectional area at the top than at the bottom in proportion to the quantity of gas passing through the pipes. Further convenient facilities have been provided to inspect and clean out the seal pots at stage floor level, while the downtake pipes are kept well away from the regenerator flues.

Suitable provision has been made for the free movement of the standpipes both horizontally and vertically. In the author's opinion the improvements introduced at Stretford are worthy of careful study by all users of standpipes.

*This figure is very close to that found in actual practice at the Ottawa Gasworks (Canada), where coal gas has been used on an extensive scale for heating continuous vertical retorts.


BALANCED, DOUBLY-SEALED GAS TIGHT CHARGING DOOR
GAS CONTROLLED INTO EACH ¼TH. OF LENGTH OF COMBUSTION CHAMBER.
'DEMPSTER-TOOGOOD' NON-CLINKERING SCREEN-BAR GRATE WITH SLIDING DOOR.
AIR PORT CLOSED.
GAS VALVE OPEN.
AUXILIARY REGENERATOR OF HORIZONTAL TUBES FOR EASY INSPECTION.
MAIN FOR GASEOUS FUEL
AIR
GAS VALVE SHUT & AIR INGRESS OPEN.
SECONDARY-AIR CONTROLLED TO EACH ¼TH OF LENGTH OF COMBUSTION CHAMBER.
MAIN FOR GASEOUS FUEL

Detail Gaseous Firing *Detail Coke Firing*

FIG. 12. FIRING IN AUXILIARY REGENERATOR, STRETFORD GASWORKS.

Fig. 13. Congdon Standpipe as Used at Stretford Gasworks.

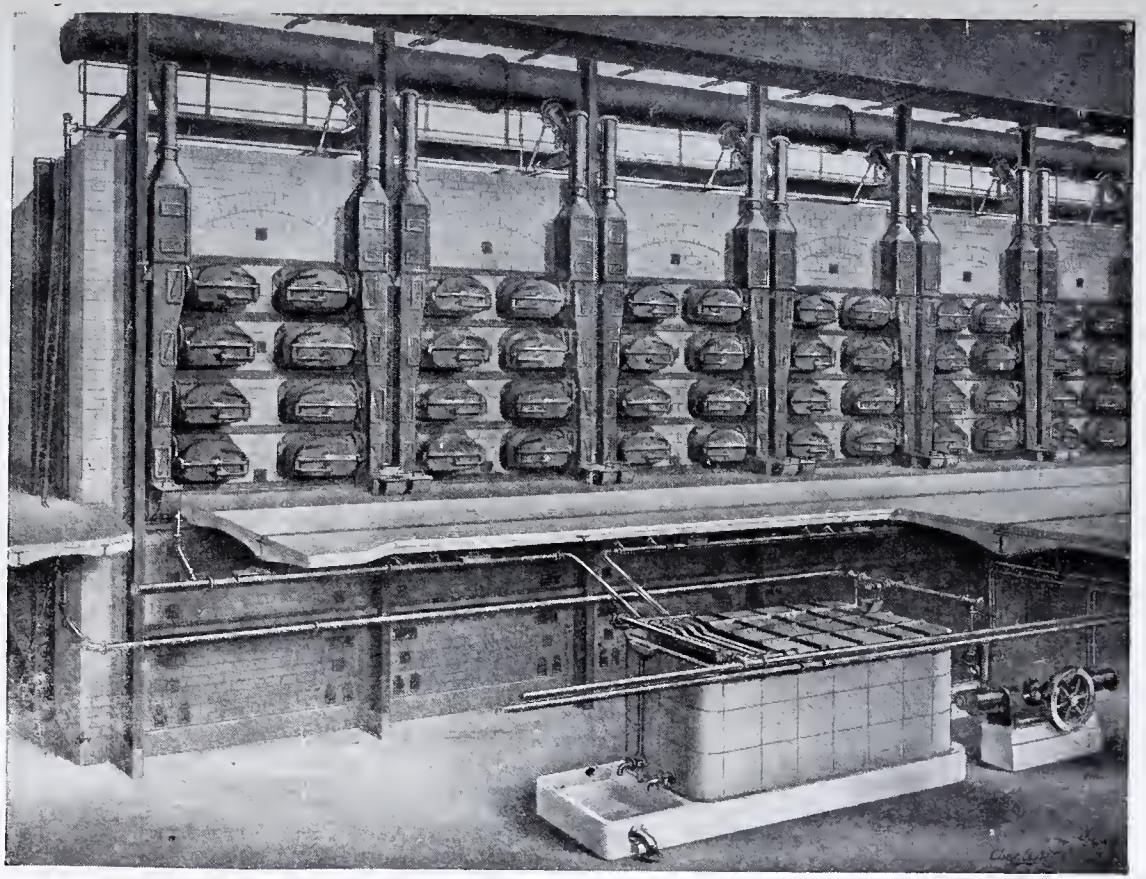


FIG. 14. CONGDON STANDPIPE AND CIRCULATING SYSTEM AT STRETFORD GASWORKS.

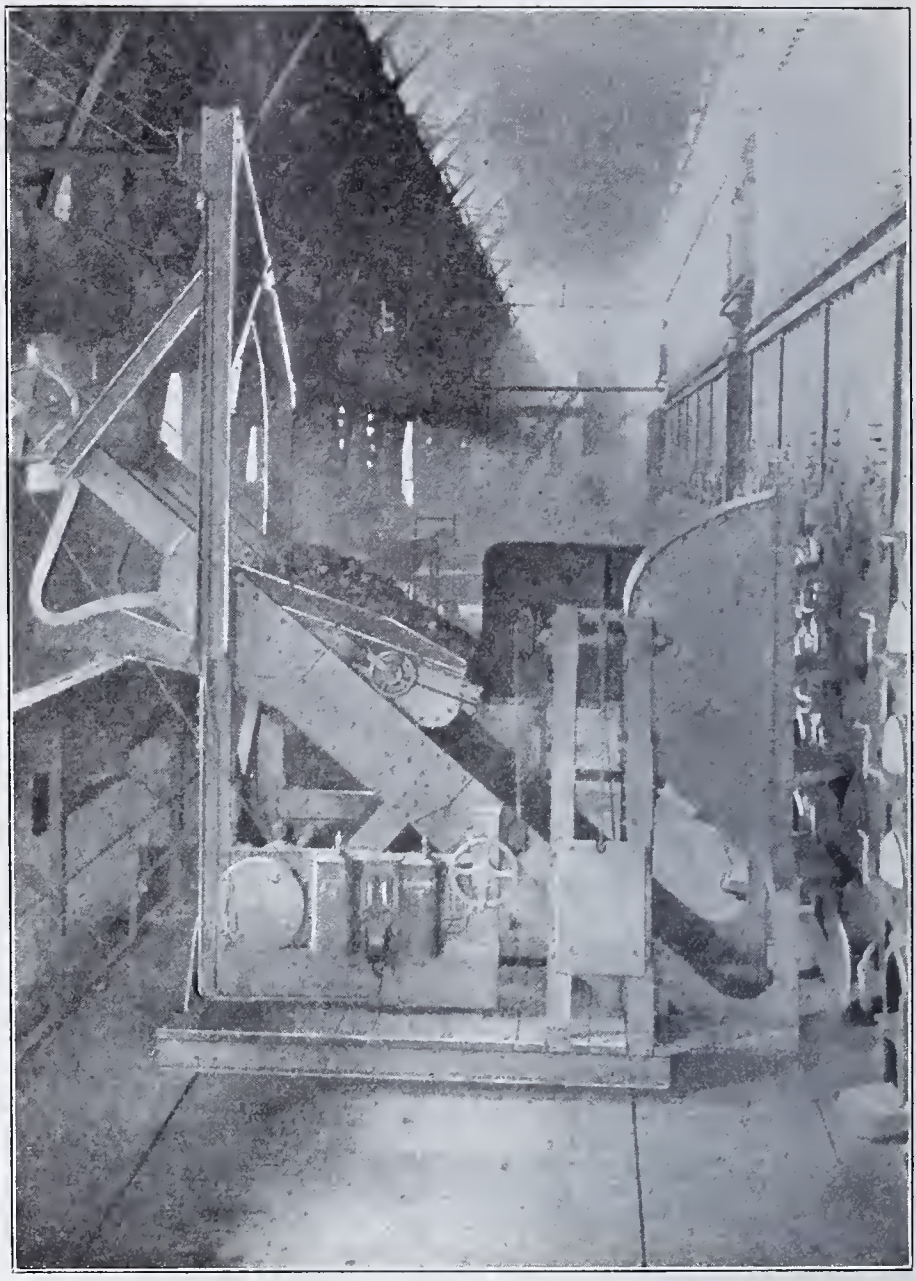


FIG. 15. DRAKE'S HOT COKE TRANSPORTER SHOWING SKIP TRAVELLING UP INCLINE.

In the Stretford retort house a Fiddes-Aldridge simultaneous stoking machine has been adopted. As is well known, this machine discharges the coke and inserts the coal in the one operation. The machine has been modified to charge a heavier weight of coal than in the older machines, and in this case it is stated that a weight of 1,900 lbs. can be used in the 22 feet of 24″x18″ D retorts.

At present 12-hour charges are employed, but Mr. Carr states that the same charge can be carbonized in 8 hours, thus leaving a considerable margin for increased throughput as gas sales increase.

In the author's opinion this is one of the most interesting horizontal installations in England, and embodies improvements which have an important share in the excellent results being obtained in normal working.

The above retort houses and their arrangements are described in some detail, as these are essentially typical of modern English practice. There are, of course, many alternative arrangements.

Drake's Hot Coke Transporter is frequently used for receiving the hot coke from the retort and delivering it to the quenching

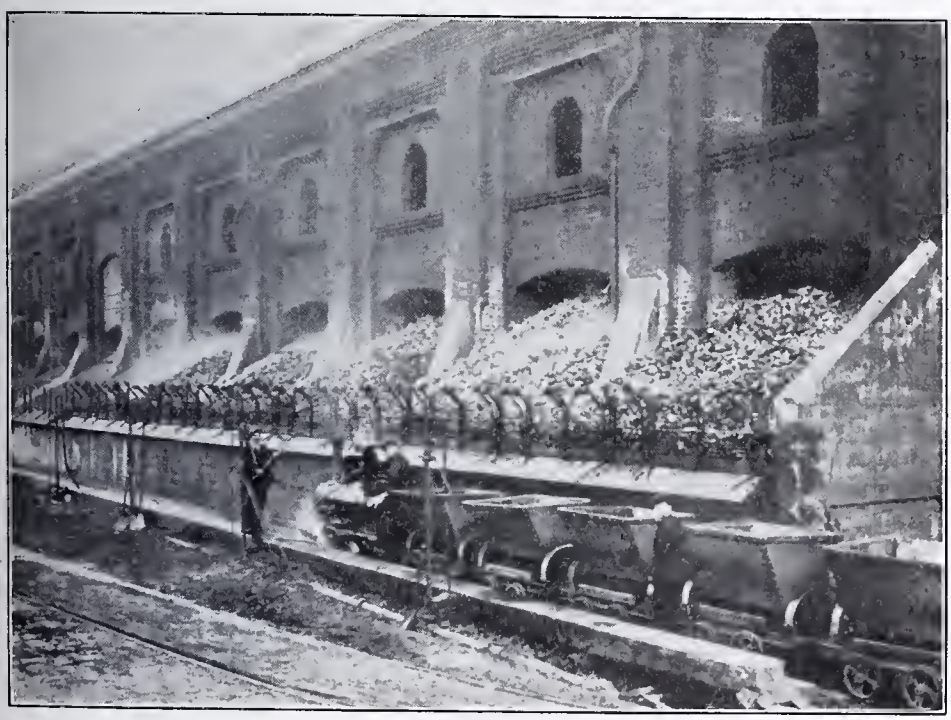


Fig. 16. Showing Coke From One Draw on Quenching Bench.

bench. This machine is shown in Figs. 9 and 15. It is mounted on a bogie running on rails in front of the retort bench, and consists of an inclined elevator with one large skip, into which the coke is delivered by means of a sloping shoot, one of which is provided for each tier of retorts. The higher the retorts the higher is placed the skip for receiving the coke.

The skip is elevated by means of two steel wire ropes and is made to tilt at the top of the elevator and deliver the coke slowly and uniformly to the quenching bench, with the object of causing it to slide down and settle in a comparatively thin and even layer ready for quenching.

The inclined quenching bench is now being used in many English retort houses. A view of a typical arrangement is shown in Fig. 16. This system has many obvious advantages over other systems in which the coke is quenched in the retort house, not the least of which is the removal of the steam from the interior of the retort house and the elimination of one of the causes of slow retort house work, as the coke can be removed and disposed of with rapidity.

Both the G-N and the Drake's Hot Coke Transporters are excellent machines for working in conjunction with coke quenching benches.

The former machine also fills the producer, but in the case of the latter a producer charging machine is used, the coke being discharged from the retort into the vertical shoot, from which it is pushed forward into the producer by the reciprocating action of an inclined feeder. This machine can be propelled by hand gear, or can be attached temporarily or permanently to the transporter above described.

Producers, however, can be so placed in relation to the retort mouthpieces as to dispense with the necessity of providing any charging apparatus, the coke merely falling directly into the producer as quickly as it is discharged from the retort. This is the best practice, but it necessitates large charging doors in the producer.

The author does not intend to describe any types of hot coke conveyors as those used in England are of the same type as those used in the United States, and besides, the later methods of hand-

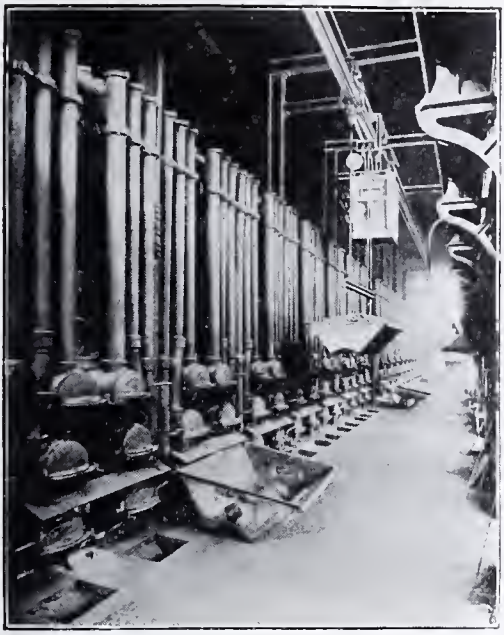


FIG. 17. TELPHER PLANT.

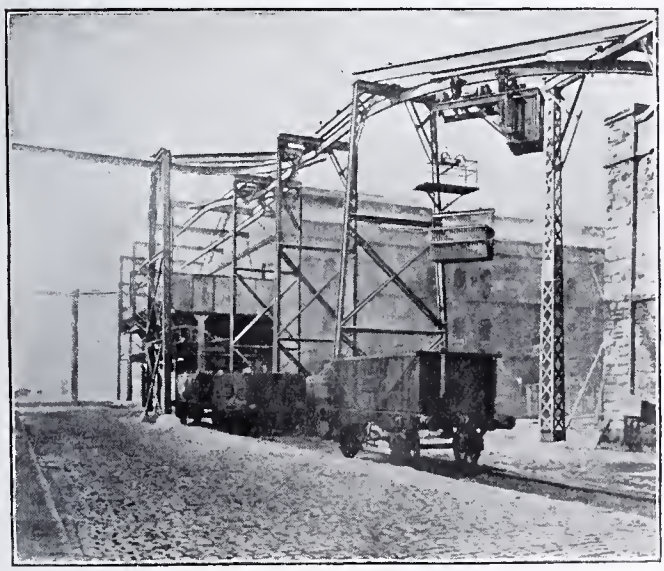


FIG. 17A. TELPHER PLANT.

ling hot coke, as described, are, in the author's opinion, superior for this purpose.

TELPHER HANDLING

In England telpher plants are frequently used for handling hot coke as shown in Fig. 17. In these cases skips are employed for receiving the coke as discharged from the retorts, these being then lifted clear of the bench and carried by a telpher machine on an overhead tract first to a quenching spray, and then to the coke screening plant or store.

This arrangement when used for handling hot coke is often criticized as being slow, and as being suitable only for medium and small retort houses. While there is some truth in this criticism this method can be considerably speeded up by employing an endless track and several machines. By such means a fair degree of speed can be maintained.

This system has several advantages. The power and maintenance costs, except for the skips, are low, the labor required is by no means excessive, and the facilities for removing the coke to any part of the works, whether it be a water gas plant. boiler plant, screen or store, are excellent. Frequently also it is possible to combine with the coke handling the handling of coal, oxide of iron, and other materials used in the works.

There are several gas works in England where all materials are handled on a telpher track designed to travel to all parts of the works, and in these cases the results have been very satisfactory.

In a paper read by Mr.S.E.Whitehead, of the Portsea Island Gas Company, in March, 1924, he states that a 3.36 ton telpher machine erected complete with motors, trolleys, and wiring, but excluding skips cost (in 1924) about $5,350, and that the complete telpher track, including trestles, lattice girders, track joists and rails, erected complete with trolley wiring, insulators, etc., but exclusive of foundations cost:

TABLE VI

Date of order	Length Feet	Height	Per Foot	Price of Steel Sections Per Ton
October, 1923	227	38′0″	$22.45	$41.00
October, 1922	400	49′9″	32.70	37.90

Considerable lengths of track were bought previously at much higher prices.

The costs of working the entire 3.36 ton telpher plant with 1500 ft. track over 2½ years, during which period 107,500 tons were hoisted and carried on the average 300 feet, was:

Table VII
COST OF TELPHER HANDLING

Conditions	Past 2½ years	Plant at full work
No. of Machines	One	Two
Tons carried per annum	Actual 43,150	Estimated 113,000
	Cents per Ton	Cents per Ton
Interest and depreciation	14	6
Maintenance	1	1
Running	1	1
Labour	6	5
Total	22	13

In this case the telpher plant receives the coke from the quenching bench, the skips do not have to handle hot coke, and it is estimated that their useful life is from 34,000 to 45,000 tons each; but if used for hot coke, as shown in Fig. 17, their life is reduced to about 6,200 tons, that is, for a skip costing $243.00.

The author gives these figures in some detail as he has often considered during his trips in the United States that there is plenty of scope for the telpher plant in American works.

Electricity Generation in Gas Works

Practically all the modern machines used for operating horizontal retort houses in England are electrically driven, and this necessitates the use of a considerable quantity of electric current.

In nearly all cases the electricity is generated in the gasworks, and in most cases dynamos are driven by gas engines. This is general practice in England.

The retort house shown in Fig. 9 is operated by a small, gas engine-driven electric generating set. In this case the plant has to serve a retort house of 48 24″x18″x23′ retorts, and consists of two 30 k.w. and one 2 k.w. sets, direct current, 239 volts. One 30 k.w. set meets

the day load requirements, the other being used as a standby, while the 2 k. w. set is used for lighting only. To drive these dynamos there are two national gas engines capable of developing 50 b.h.p. at a normal speed of 30 r.p.m. The small gas engine running at 475 r.p.m. develops 3½ b.h.p. as a constant working load.

On the larger works it is usual to provide for two large sets, one acting as standby, for the day load, and one set considerably smaller for the night load, when coal and coke handling and other auxiliary plants are shut down.

For small gas works in Great Britain—and there are over 1,000 making less than 100 million cubic feet per annum—it is considered that power-operated stoking machines are not justified. In suitable cases manual charging machines are used, one of the best being shown in Fig. 18.

In this case the scoop machine can be conveniently worked entirely by one man. To fill it with coal it is lowered to the ground

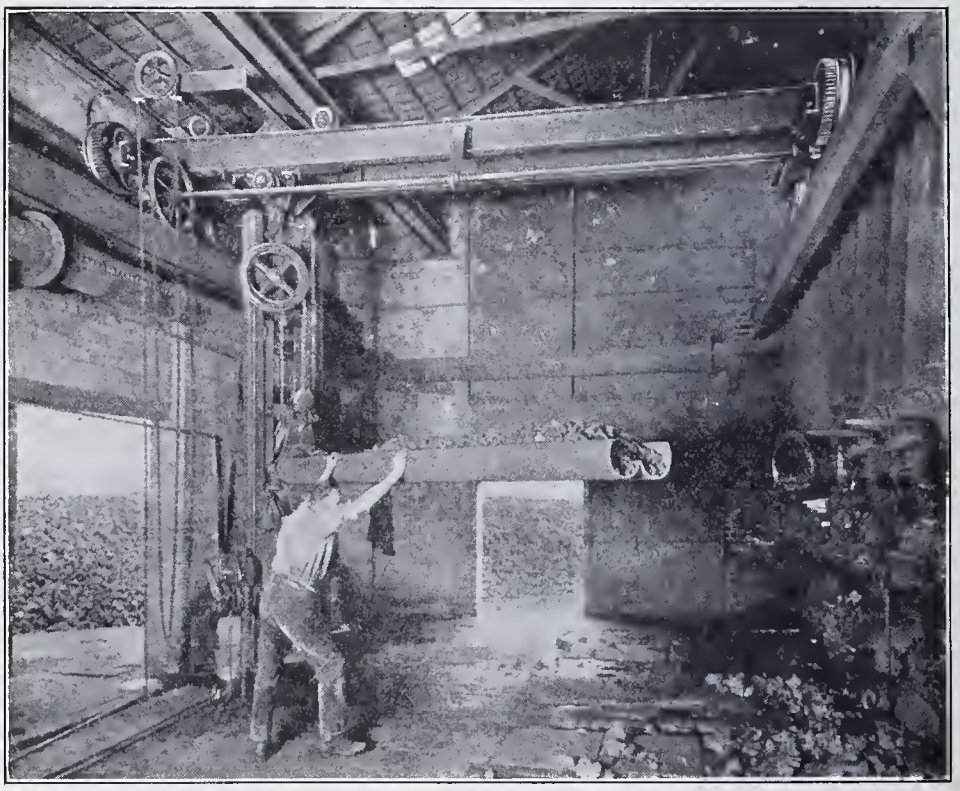


FIG. 18. MORRIS RETORT CHARGER.
Swinging the scoop into line.

level and slewed round in a direction at right angles to the retorts and is then filled by hand or from hopper doors. It is then lifted by hand lifting gear, slewed round and run into the retort by the charging gear and turned over. It is then withdrawn ready for the next retort.

In France there are several excellent designs of small manual drawing machines for stop-ended retorts, but in England this work is nearly always done by hand rakes.

Carbonizing Practice in London

Horizontal retort settings are used on a large scale by the London and suburban gas companies, and it is probably true that 90 percent of the coal carbonized by such companies is in horizontal retorts, the balance being in verticals.

Considering that London and district use 26.9% of all the coal carbonized in Great Britain, it follows from the figures mentioned elsewhere in this paper that the rest of the country carbonizes nearly 70% of the coal in continuous vertical retorts and other systems, these latter being on a virtually infinitesimal scale and not deserving of special mention.

There is, of course, a reason for this large use of horizontal retorts in London. London being situated on the river Thames, the various gas works have sites on the water side and consequently take delivery of their coal in ships. Of the various coal fields Durham is the only one with good facilities for the loading of ships, and as a result by far the larger portion of coal used in London gas works comes from the Durham coal fields.

Of all the gas coal produced in England that from Durham has the most pronounced coking properties, with strong tendencies to swell during carbonization. It contains also a considerable proportion of fine coal, this being frequently in excess of the rough coal.

For many years these properties presented a difficult problem to the vertical retort builders, and it has only been during the past ten years that this problem has been properly solved, and now Durham coal is being successfully dealt with in vertical retorts in many gas works.

This at any rate explains the reason for the preference extended to horizontals in London and other areas where seaborne coal is substantially cheaper than railborne coal. As elsewhere, trans-

port by sea is much less than that by rail for similar distances, and to London seaborne coal probably costs for freight from 25 to 35% of that entailed in railway charges.

However, horizontal retorts have been successfully used in London for many years, as the following summary of the latest results indicates:

TABLE VIII

Results of Three London and Four Suburban Gas Companies

Total annual coal carbonized	4,570,000 tons
Gas made	5.9 cu. ft. per lb. or approx. 62.5 therms
Coke and Breeze made for sale	1140 lbs. per ton of coal (about 1020 lbs. coke only)
Tar made	10.3 gallons
Ammonia	5.7 lbs.

N. B.—Cost figures are not given, as these are unfortunately rendered useless by being combined with costs of water gas manufacture in the various published statistics.

As will be appreciated, the horizontal retort is by no means dead in England, and every year new improvements are introduced to keep it as a lively competitor of its younger rival—the continuous vertical retort.

THE CONTINUOUS VERTICAL RETORT

The continuous vertical retort was first introduced in England and has been developed most successfully by two large British firms, the Woodall-Duckham and the West's Gas Improvement Companies, and to a much smaller extent by two or three other firms.

The first Woodall-Duckham installation was put to work at Bournemouth, England, in 1907, and the first Glover-West installation at the St. Helen's Gas Works (England), in 1908. Since then these two firms have been most progressive and enterprising in their methods, and as a result the continuous vertical retort is a highly efficient type of carbonizing plant.

The progress made by the continuous vertical retort is undoubtedly the most important English development in coal carbonization during the past 20 years.

Since the first installations above mentioned there has been a wonderful growth in this type of plant, and now the gas making

capacity of continuous vertical retorts in the British Isles amounts to approximately 450,000,000 cubic feet per diem. The author estimates that these plants are making about 53% of the total coal gas made, or approximately 42% of the total gas made, including water gas.

Some Reasons for Its Growth

This shows a remarkable growth in the use of continuous vertical retorts, and is due to:

1. The progressive methods adopted in improving the design and operation of the system.
2. The large amount of gas made per sq. ft. of ground area.
3. The small amount of labor required to operate the plant.
4. Its adaptability to works of medium and small size.
5. The absence of nuisance arising from gas making in residential areas.
6. The uniformity in quantity and quality of gas produced.
7. Its flexibility in the matter of quality of gas which can be economically made.
8. The coke produced being dry and exceptionally combustible with low draught.
9. The high yield of gas and liquid products per ton of coal carbonized.
10. The low quantity of fuel required, especially having regard to the waste heat boiler development.

The above percentage is steadily growing at the expense of horizontal and inclined retorts, though many old installations of these types are replaced by modern plants of the horizontal type as noted above.

The Glover-West Syetem

The retorts, which are set in units of four, measure 25′ 0″ long, and are of elliptical shape, the top internal measurements being 33″ x 10″ tapering outwards towards the base, finally extending to a circular chamber at the bottom of 39″ in diameter.

At the bottom of the retort is fitted the coke extractor consisting of a slowly rotating spiral screw, which lowers the coke continuously into the storage hopper at the base of each retort, the coke being finally discharged at intervals into wagons or other types of conveying plant.

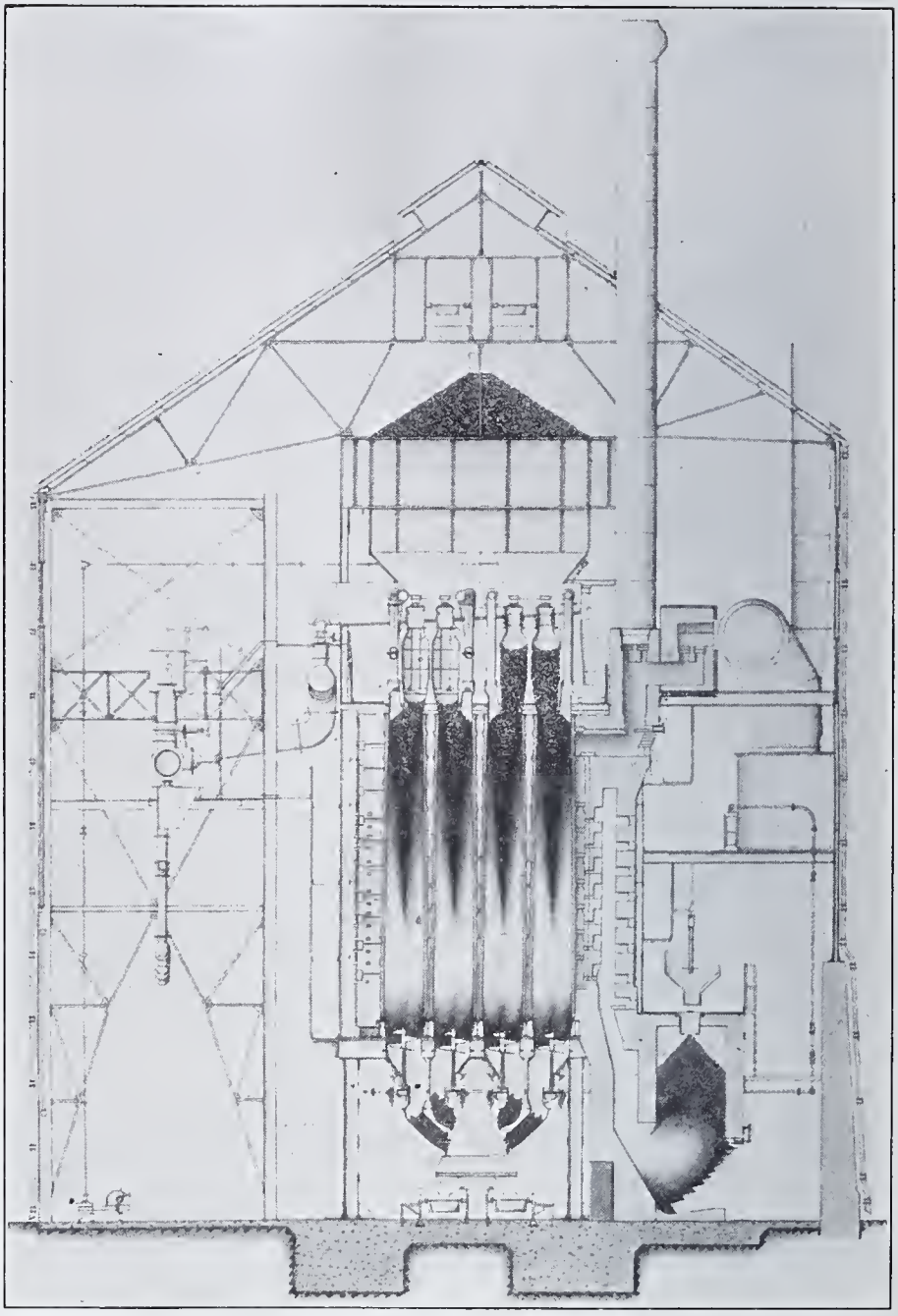


Fig. 19. Cross Section of the Glover-West Vertical Retort House.

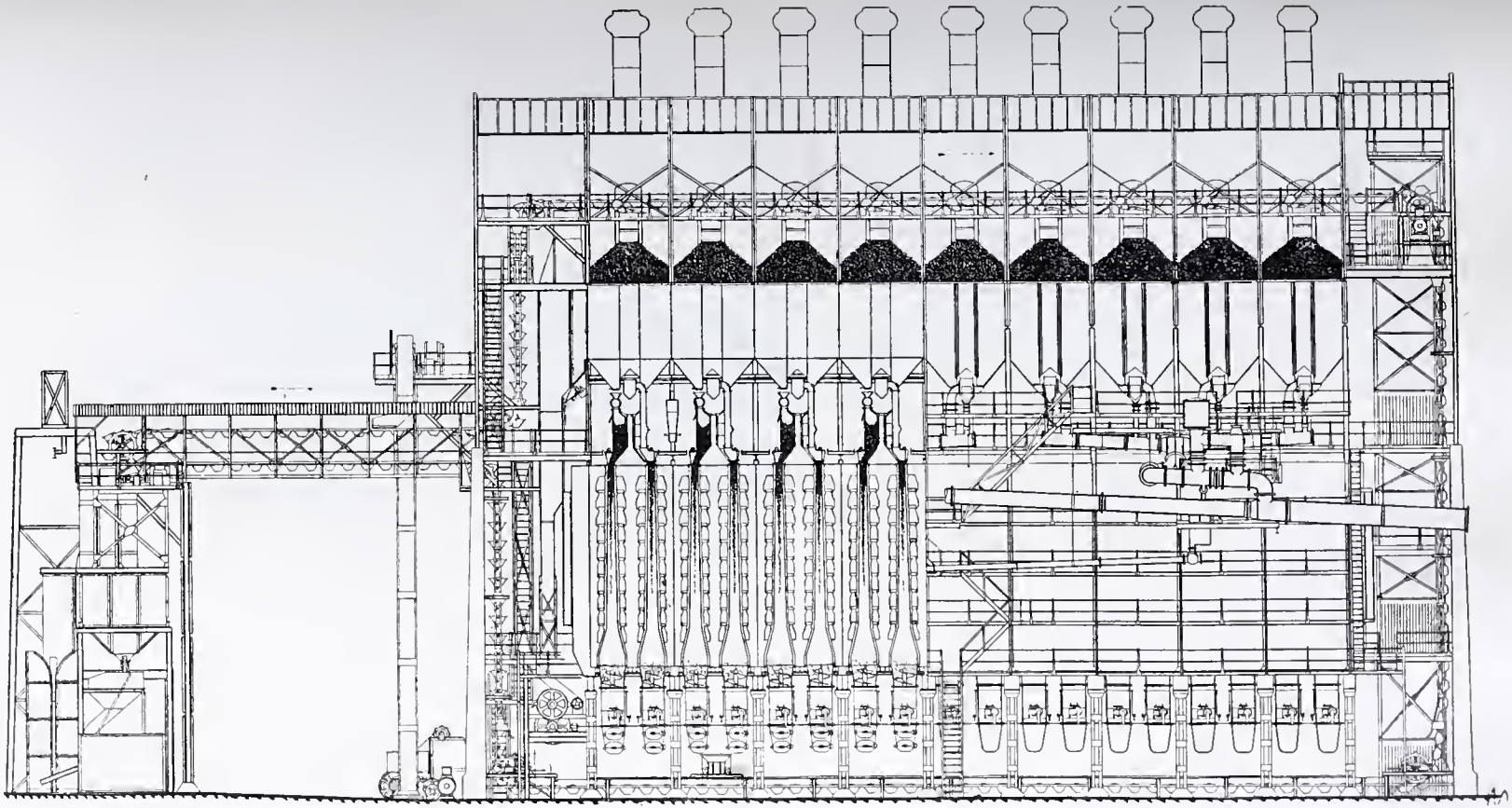


FIG. 20. LONGITUDINAL SECTION OF GLOVER-WEST VERTICAL RETORT PLANT.

The speed with which the coke is extracted is readily adjustable and determines the rate of inflow of the coal at the top of the retort.

The coal is supplied intermittently to small hoppers attached to the top of each retort and from these it flows continuously into the retort in accordance with the amount of coke extracted.

The retorts are heated by producer gas fired in horizontal flues, the waste gases finally passing through flues surrounding the top portion of the retorts before entering the waste heat boiler. The secondary air is heated in flues constructed in the base of the retort by the outgoing coke.

Each retort as now constructed is capable of producing over 90,000 cubic feet per 24 hours.

FIG. 21. NEW MODEL GLOVER-WEST RETORT.

The illustrations shown in Figs. 19, 20, 21 and 22 are, it is thought, sufficiently clear to enable the general principle of the plant to be understood without further description.

The Woodall-Duckham System

In this system the retorts are made of 3 sizes with coal through-puts of 3.36, 5.6 and 7.85 tons per 24 hours respectively, but recently an installation of 11.2 ton retorts has been put in operation.

The retorts are of rectangular shape tapering from 8 inches at the top to 1′ 7″ at the base, the major axis tapering only 3 inches from top to bottom, but varying in length at the top from 3′ 11½″ to 6′ 3″ according to the size of retort required.

The retorts are constructed 25 feet in length, though the 7.85 ton size is sometimes 26 feet long.

The coke extractor provides for a continuous discharge of coke throughout the whole period of gas making, while the water-sealed

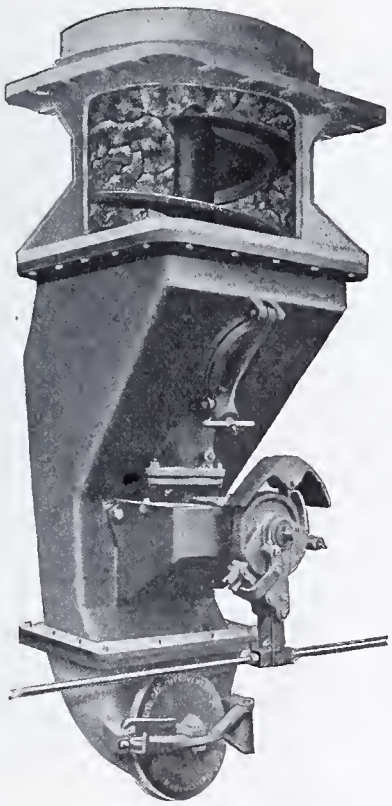


Fig. 22. Glover-West Coke Extractor.

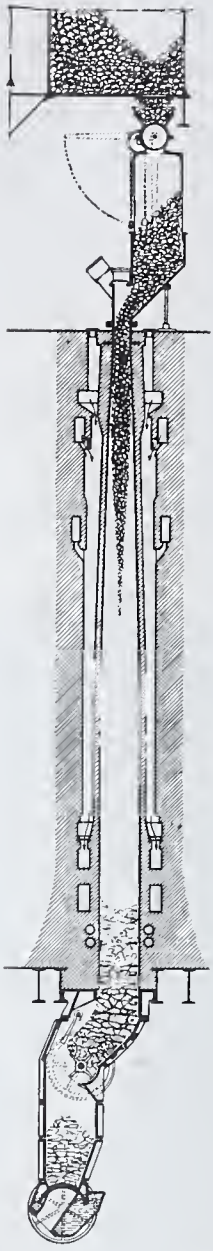
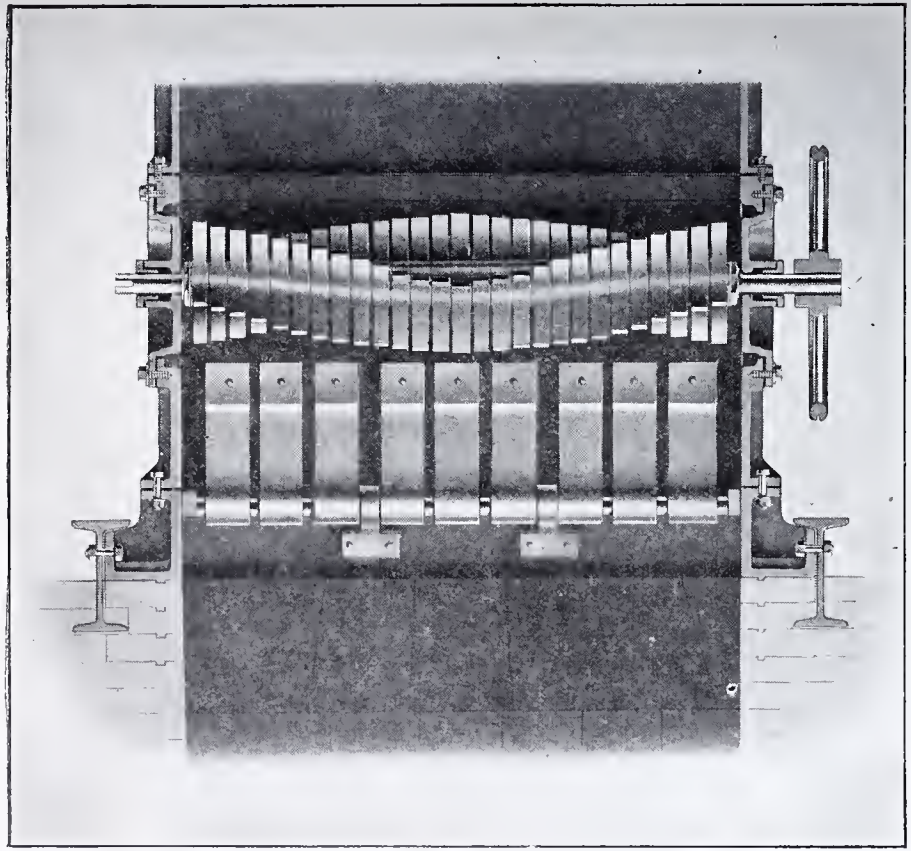


FIG. 23. DIAGRAM OF W-D VERTICAL RETORT.



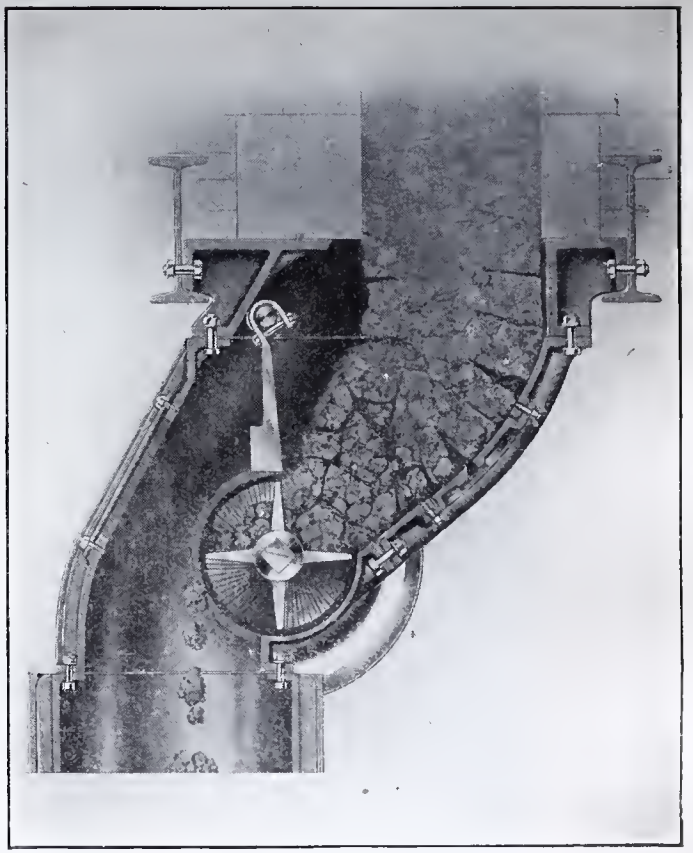


Fig. 24. Fig. 25.

Arrangement of Coke Extractor and Coke Hopper for W. D. Vertical Retorts.

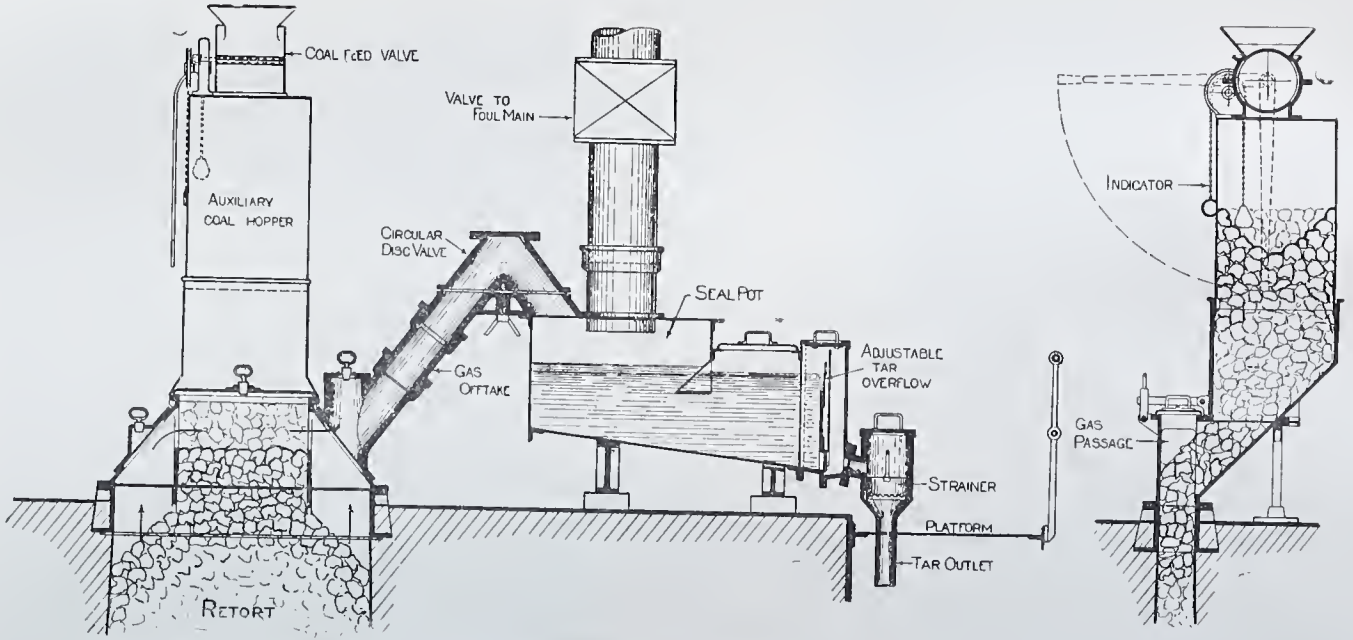


FIG. 26. AUXILIARY COAL SUPPLY HOPPERS, GAS OFFTAKES, ETC., ON W. D. VERTICAL RETORTS.

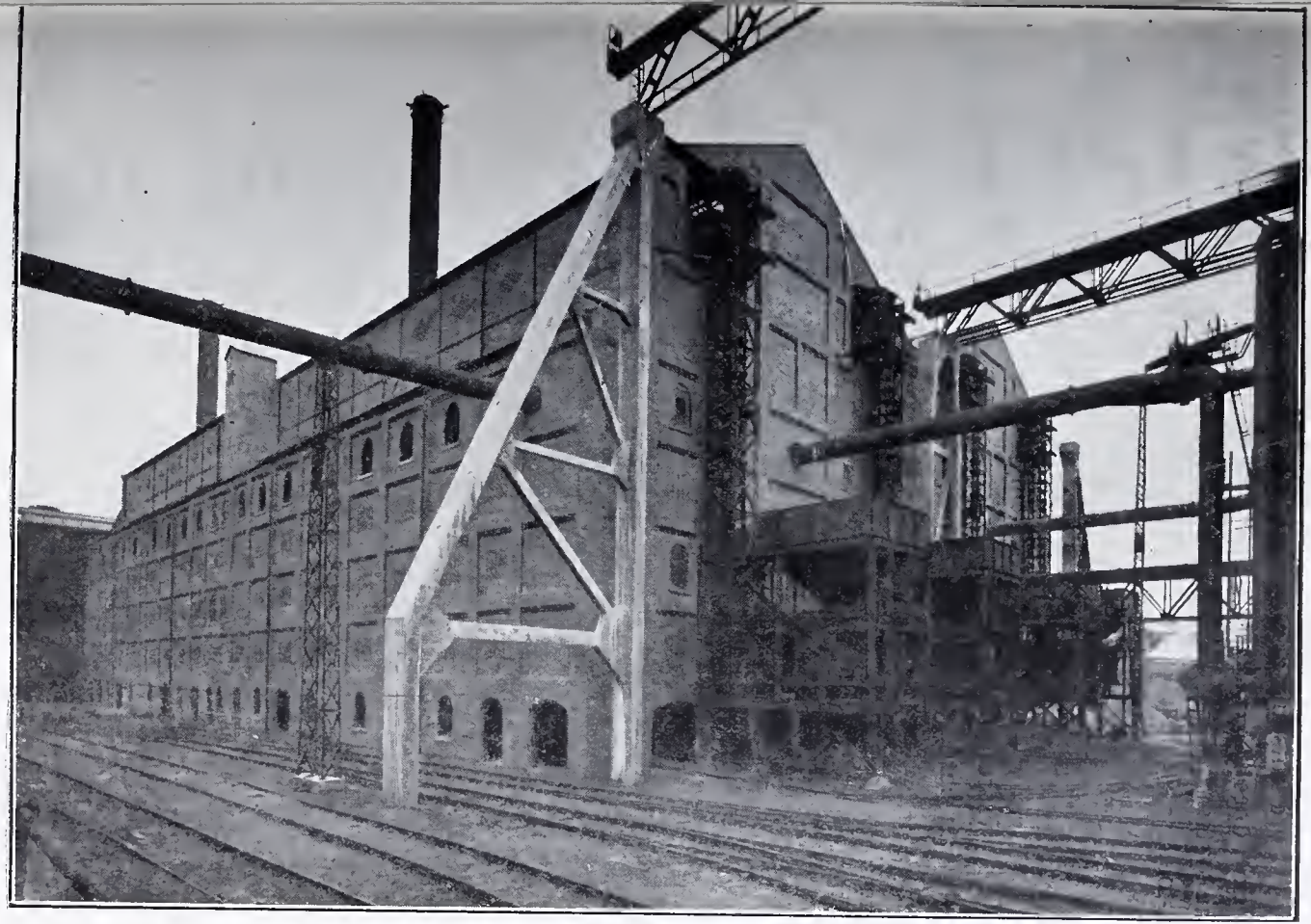


FIG. 27. GLASGOW (PROVAN GAS WORKS.)

This, the largest installation of Vertical Retorts in the world, was erected for the Glasgow Corporation Gas Department at their Provan Gas Works, and was officially opened in September, 1922. It consists of eight benches each of twenty-four 7.85-ton retorts. W. D. system.

door, normally closed, is rotated and opened at intervals to discharge the coke which has accumulated. The door, being sealed in water, effectually prevents any admission of air or emission of gas. The coke, on its exit, does not come into contact with the water in the seal.

The system of coke extraction, coal feed and gas exit will be clearly understood from the illustrations, Figs. 23, 24, 25 and 26.

The producers are fitted with step grates and are situated in close proximity to the retorts.

The system of heating the retorts is by a downward passage of gases as shown in Fig. 23, the exit being at the base of the retorts, after which the waste gases pass through a recuperator, thus heating the secondary air before finally flowing through a waste heat boiler.

The retorts are constructed of panelled bricks with the object of enabling an easy transference of heat while providing for strength in the wall.

The steam used in the retorts is superheated in flues in the lower portion of the retorts prior to entering the retorts through nostril holes, as seen in Fig. 23, provided below the bottom of the heating flues.

Fig. 27 shows the exterior of the largest vertical retort plant in the world, this consisting of 192 Woodall-Duckham 7.85 ton retorts to make 20 million cubic feet per day, and was erected at the Provan Works of the Glasgow Corporation (Scotland) in 1922.

The Development of Steaming

The developments which took place during the War—1914-1918—account for a very distinct improvement in the design and results. At that time tar became of vast importance on account of the great demand for high explosives and for liquid fuel, and all sorts of measures were adopted to increase the quantity of tar available. It was rightly considered, and, in fact, it had been proved many years previously by Prof. Vivian B. Lewes, that if the gas as produced could be protected from the radiating effects of the hot internal surface of the retort and of the incandescent coke in the retort it would result in more hydrocarbons and more tar and ammoniacal liquor safely arriving into the condensing system.

Methods were therefore introduced to protect the gas and liquid products by admitting steam at the bottom of the retorts, thus quenching the coke before its extraction and converting a part of

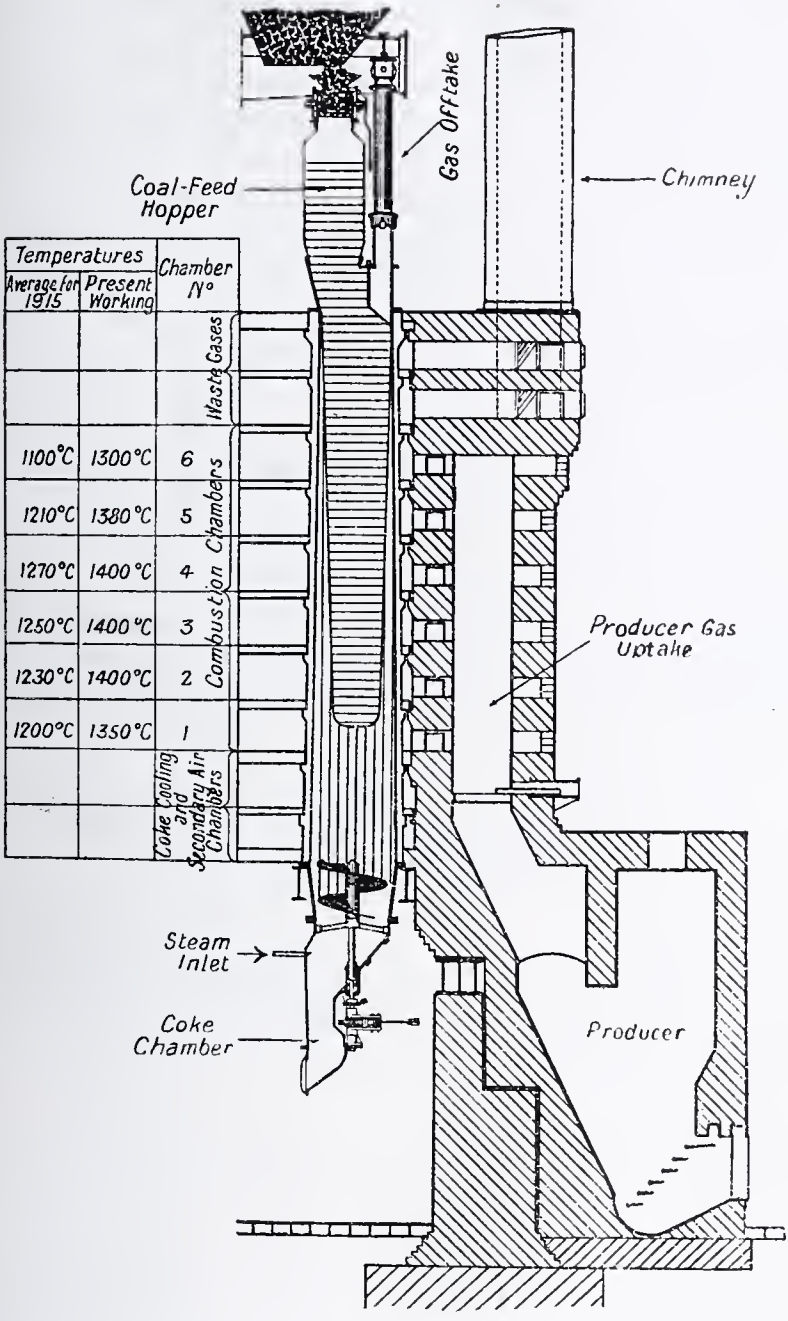


FIG. 28. DIAGRAM ILLUSTRATING THE SYSTEM OF HEATING THE GLOVER-WEST RETORTS AT THE MACCLESFIELD GASWORKS IN 1917.

the coke in the lower portion of the retort to water gas, which gas on its passage through the charge would effectually protect the coal gas in the desired manner.

This system succeeded far above anticipation and resulted in improvements both in gas production and in the yield of tar and ammonia to an extent which substantially assisted the continuous vertical retort system to compete on equal terms with modern horizontal systems, even in the matter of capital costs in which direction it had not hitherto competed favorably.

The continuous vertical retort is now therefore a combined coal carbonizing and water gas producing apparatus.

It was anticipated by many that the steaming of the coke would deteriorate its quality by removing the carbon and so increasing the ash content. This has not been its effect, as indeed is shown as the result of the tests carried out by the Fuel Research Board.

This can be explained by the fact that the water gas reaction is a surface one and robs the coke of its carbon on the surface only, to a large extent. The ash thus freed drops from the coke and is found with the dust. A study of the results obtained with gradually increased steaming and of the analyses of the coke produced shows

TABLE IX

EARLY EXPERIMENTS IN STEAMING VERTICAL RETORTS AT MACCLESFIELD GAS WORKS

Results Before and After the Alteration

	Average for Year Ending March 31, 1915	Average of 2 Tests Made in June and August, 1917
Gas made—cu. ft. per lb.	5.4	6.9
Calorific Value per cu. ft.	530 B.T.U.	509 B.T.U.
Analysis of Gas:		
CO_2	2.4	2.5
C_nH_m	2.4	2.3
O_2	Nil	Nil
CO	9.8	12.1
CH_4	23.9	22.7
H_2	53.2	52.0
N_2	8.3	8.4
	100.0	100.0
Total Inerts	10.7	10.8
Coke discharged from retorts per ton of coal	1360 lbs.	1336 lbs.

that there is no marked deterioration as a result of such increase in steaming.

Some of the first practical experiments carried out in the steaming of vertical retorts were made by Mr. J. E. Blundell, at the Macclesfield Gas Works, in 1916 and 1917, and by Mr. John West before the Royal Society of Arts, London, on November 8, 1917.

Mr. Blundell, in a paper read before the Manchester District Institution of Gas Engineers on October 27, 1917, reported that by increasing the temperatures of a vertical retort plant to that shown in Fig. 28, and by using a larger amount of steam than that required for cooling the coke he obtained the results set out in Tables 9 and ten.

Table X

EFFECT OF STEAMING ON AMMONIA AND TAR PRODUCED AT MACCLESFIELD GAS WORKS

	During Year Ending March 31, 1915	During 3 Months Ending August 31, 1917
Ammonia produced per ton of coal..	5.00 lbs.	6.45 lbs.
Tar per ton of coal.....	11.65 gals.	16.61 gals.

He further stated that in making the above grade of gas he calculated that the loss in coke for sale per ton of coal carbonized is made up as follows:

		Lbs.
(1)	Carbon converted into water gas in the retort..	22.3
(2)	Extra fuel supply to the producer to effect the water-gas reaction	22.3
(3)	Fuel supply to boilers to generate steam.....	21.5
	Total	66.1

These results were received with some surprise but great interest at the time, but were not then, nor have they since been seriously questioned. In fact, these results have been confirmed and considerably improved during recent years by Mr. Blundell himself, now at Carlisle, and by many others.

This development was considered to be a matter of first-rate importance and the investigation of the system was placed in the scientific hands of the Fuel Research Board.

Table XI

RESULTS OF STEAMING IN CONTINUOUS VERTICAL RETORTS AT THE FUEL RESEARCH STATION, EAST GREENWICH, LONDON

N.B. The figures below are compiled from the various Reports issued by the Fuel Research Board

COAL USED	Test	Analyses of Coal used				Steam used per cent of coal	GAS		Coke % made on weight of coal	COKE Analyses of Coke produced				Tar per ton of coal Lbs.	Ammonia per ton of coal Lbs.	Gas made per retort per day Therms	Total heat value of gas used for heating retorts, in therms per hour
		H_2O	Vol.	C.	Ash		Per ton of coal Therms	Calorific value B.T.U. per cu.ft.		H_2O	Vol.	C.	Ash				
Consett (Durham)	A	1.22	26.14	62.38	10.26	Nil	60.5	510	75.2	0.38	0.17	85.72	13.73	86.5	3.4	169	17.97
	B	1.21	26.78	61.11	10.90	5	62.5	518	75.0	0.30	1.06	83.65	14.99	91.0	3.8	177	16.76
	C	2.10	26.35	61.97	9.58	21	70.5	463	73.9	0.62	0.88	85.10	13.40	102.5	4.7	198	19.02
Mitchell Main	D	1.03	30.53	59.04	9.40	Nil	63	544	72.34	0.33	0.25	89.3	10.1	92	3.6	180	19.15
Gas Nuts (Barnsley)	E	0.81	30.32	52.32	6.55	5	76	517	69.4	0.18	0.31	89.4	10.1	114	4.2	210	16.80
	F	1.10	30.81	58.51	9.58	12	86	477	66.5	0.33	0.41	86.5	12.8	111	4.9	245	19.28
	G	0.82	30.69	60.41	8.08	21	93	460	66.2	0.89	0.40	89.2	10.2	122	4.9	257	20.65
	H	1.28	29.90	60.96	7.86	30	98	432	63.8	0.23	0.05	84.2	15.5	125	4.9	278	22.41
Lanarkshire Main	J	9.87	30.16	52.41	7.56	Nil	54	518	61.2	0.31	0.81	88.2	10.7	136	7.3	199	18.36
	K	9.72	31.21	52.71	6.36	22	71	432	54.9	1.13	2.35	84.4	12.1	172	9.8	293	19.60

The Fuel Research Board tests reported in 1921 are here included in an abbreviated form. These give the results obtained in a full-scale Glover-West Vertical Retort plant, as installed at the Fuel Research Station, London.

It should, however, be pointed out that these tests were made in a plant which was not specially designed to carry out the steaming process, as is the case with more recent plants.

The above summary compiled from the valuable and interesting series of tests conducted with skill and great accuracy by the Fuel Research Board of the British Government makes it perfectly clear that the process of steaming in a continuous vertical retort is of the utmost value, and has enabled an important step forward to be made in the science of the carbonization of coal.

To comment briefly on the results:

In each case steaming substantially increases the thermal yield of gas, tar, and ammonia per ton of coal carbonized, and of the gas yield per retort per 24 hours.

The amount of fuel used is increased with steaming, but not in proportion to the increased yield of gas.

For instance, with the first coal the thermal value of the gas made per retort increases by 17%, but the fuel increases by 5.8% only. With the second coal the thermal value of the gas made per retort increases 54%, but the fuel increases by 17% only. With the third coal the thermal value of the gas made per retort increases 47%, but the fuel increases by 6% only.

In each case a very substantial gain is shown from the increased fuel used.

From the analyses of the coke it will be seen that there is a tendency for the ash content to increase with steaming, but this is not at all definite.

Other and similar tests have been made on various coals, and all showed marked improvement in results, though this varies in amount with different classes of coal. Some coal lends itself more readily to this process than does other coal, and much work has been and is being done to discover the reasons.

During 1917 and the succeeding years, important steps were taken by the West's and Woodall-Duckham Companies to adapt their systems to the steaming process.

In the case of the Woodall-Duckham Company a definite change was made from fireclay and siliceous to high percentage silica materials for the middle sections of the retorts, and a re-arrangement of the refractory materials used, while the shape of the retort was altered and an additional combustion chamber was added to increase and render more flexible the temperature at the zone between coal and coke, and so provide for the water gas reaction.

As a result, the makers claim that they have been enabled to guarantee a higher output of 50% from a given unit of plant.

In the case of the West's Company a new design, shown in Fig. 21, called the "New Model" retort, was developed. This consisted of increasing the length of retort and adding an enlarged bottom section of 39″ in diameter shape for a length of 4′ 0″, making a total of 25′ 0″.

The retorts are in this way fitted with a steaming chamber, the function of which is to provide a zone in which the hot coke is available for raising the temperature of the steam to that of dissociation before it reaches the retort proper, thus securing the advantages of steaming without reducing the heat required for carbonizing the coal.

This alteration, combined with minor alterations, made a surprising improvement by increasing the through-put of coal by 50% per retort, and the volume of gas from 50 to 100%.

As a result the capital cost of the plant has been reduced to its pre-war basis.

The effects of the steaming process and the improvements made in the design of the continuous vertical retorts are reflected in the published results of tests and of long period working, but the amount of recent information is somewhat limited, as in so many cases gas from other plant is mixed with that from the verticals.

However, such figures as are available confirm generally the test results obtained at the Fuel Research Station included above in this paper.

Appended herewith are the results being obtained from continuous vertical retorts in all the undertakings which use little or no water gas and make all or practically all their gas in verticals.

Returns of undertakings making both coal and water gas are apt to be incorrect, and are therefore excluded.

TABLE XII

ENGLAND AND WALES

12 Gas Undertakings

Total Coal carbonized - - 512,000 tons]
Calorific Value of Gas - - from 500 to 420 B.T.U. (gross)
Average - - 456 B.T.U. (gross)

AVERAGE RESULTS from a variety of Yorkshire, Lancashire and Midland coals

	Gas Produced		Coke & Breeze available for sale lbs. per ton	Tar produced gallons per ton	Net cost of Coal per 1000 cu. ft. cents	Carbonizing wages per 1000 cu. ft. cents
	cu. ft. per lb.	Therms per ton				
Average	7.7	70.0	870	16.1	18.2	4.6
Highest	8.8	77.0	1120	18.4	27.7	6.2
Lowest	6.8	62.0	710	13.8	12.8	2.5

TABLE XIII

SCOTLAND

10 Gas Undertakings

Total Coal carbonized - - 197,000 tons
Calorific Value of Gas - - from 500 to 410 B.T.U.
Average - - 453 B.T.U.

AVERAGED RESULTS from a variety of Scotch coals

These figures refer to all the 10 undertakings

These figures refer to 4 undertakings only.

	Gas Produced		Tar produced gallons per ton	Coke & Breeze available for sale lbs. per ton	Net cost of Coal per 1000 cu. ft. cents	Carbonizing wages per 1000 cu. ft. cents
	cu. ft. per lb.	Therms per ton				
Average	7.1	53.5	17.4	870	11.7	5.3
Highest	8.3	70.0	21.5	980	16.2	8.4
Lowest	6.1	58.2	8.9	750	1.2	3.5

N. B.—The above figures in Tables XII and XIII are taken from the latest published statistics at this date (October, 1926).

As regards the above figures it will be noticed that the coke and breeze available for sale is low in comparison with that from ovens and horizontals, but it must be borne in mind that the coke is dry, or practically so, and that a certain portion has been used for (a)

extra fuel required for heating retorts when steaming, (b) carbon required for water gas reaction in retort, and (c) extra fuel required for raising steam.

These latter requirements probably consume 100 lbs. of coke per ton of coal carbonized, and if it be assumed that the same coke, if water quenched, would contain at least 50 lbs. of water in ordinary gas works practice, it will be seen that the addition of 150 lbs. of coke to that available for sale per ton of coal carbonized would put this figure in close comparison with other systems. It may be added that the absence of water in the coke is considered an advantage of much importance as increasing its market value.

It should be further explained that the term "net coal" in England is the cost of coal after deducting from it the prices realized for residuals. Included in these items will be the cost of handling the coal and the residuals.

The figures for ammonia, which are, however, well above the average for carbonizing plant, are not included in the above tables as unfortunately the ammonia product is not nearly so valuable as formerly, and has for the time being become virtually unimportant.

These results, as detailed in Tables XII and XIII, are affected adversely as regards coke and breeze for sale by the fact that these particular undertakings have no water gas plant, and have, therefore, to keep retorts standing by to meet increases in the demand for gas, thus consuming fuel and decreasing the quantity available for sale.

Below are outlined results based upon the guarantees given by the builders when installing new plant. These may be taken as being fairly representative of the results obtained from modern vertical plant using average qualities of English coal.

Verticals for Small Works

In England there are over 30 installations in gas works making less than 100 million cubic feet of gas per annum, the smallest being one of 2 retorts in a works making 17 million cubic feet per annum.

In these small installations the only difference made is in the provision of a similar type of coal and coke handling plant, this

Table XIV

Results from Continuous Vertical Retorts Using Waste Heat Boilers

Based Upon Guaranteed Tests With an Average Quality of English Coal

	Per Ton
Coke made	1300 lbs.
Coke used as fuel	270 lbs.
Coke made for sale	910 lbs.
Breeze made for sale	120 lbs.
Total salable	1030 lbs.
Tar made	18 gallons
Ammonia	6.75 lbs.
Gas	15,000 cu. ft. of 475 B.t.u.
	= 6.7 cu. ft. per lb.
	= 71.5 therms per ton

being in many cases confined to a coal elevator or hoist only.

Even the smallest plants are provided with waste heat boilers, these frequently being of the natural draught type.

Fuel Used for Carbonizing in Continuous Vertical Retorts

With one exception none of the published statistics relating to gas undertakings include "Fuel" as a separate item, and, unfortunately, only two of the undertakings included in the above tables are dealt with in the statistics referred to above.

Numbers of tests over long and short periods show that fuel consumption ranges from 11.0 to 17.0 lbs. of coke as fired per 100 lbs. of coal carbonized. The average of such tests is 13.6 lbs. and covers a range of cokes practically dry and with an ash content probably varying from 8 to 20%.

In these tests the calorific value of the gas produced averaged 476, this being a factor of which account must be taken in considering fuel consumptions.

Labor

The number of operators on continuous vertical retort plant per unit of gas produced varies proportionately with the size of the plant.

In England each man employed on a vertical retort plant will produce from 600 to 1000 therms of gas for his day's work—that is from 120,000 to 200,000 cubic feet of gas of 500 B.t.u. per man per day, from the coal in the wagon to coke delivered to screening plant.

The author believes that with similar plants in the United States the gas made per man is considerably higher, as plants generally are run with less labor here than in England. The men are here paid higher wages and more work is expected per man employed.

Apart from this, it is considered in England that results can easily be unfavorably affected by stinting the amount of men employed, and that the provision of a sufficiency of labor is a true economy.

MAINTENANCE COSTS

In a paper read by Mr. Buckley, of the Manchester Gas Works, in which he gave very complete details of the various maintenance items, the total was given as 16.6 cents per ton of coal carbonized or 1.4 cents per 1,000 cubic feet over a period of 11 years from July, 1910, to May, 1921. Of the above 11.7 cents per ton was spent on retorts and producers only.

Mr. J. M. Campbell, of Margate, in carbonizing 196,000 tons from 1914-1922 in Woodall-Duckham vertical retorts spent $28,400 on maintenance, this amounting to 14.4 cents per ton of coal carbonized. Of this figure 12.6 cents was spent on retorts and producers only.

An amount varying from 14.5 to 18 cents per ton can probably be taken as the approximate cost of maintenance of continuous verticals under English conditions.

CAPITAL COSTS

In a paper by Mr. George Evetts, read before the Institution of Gas Engineers in 1925, he estimates the cost of vertical retort plant at $243,000, for a complete plant including coal stores, power plant, and preliminary condensation, to make 10,000 therms, i. e. 2 million cubic feet of 500 B.t.u. per cubic foot. This figure is now considered a high one by the makers, who have quite recently been able to reduce

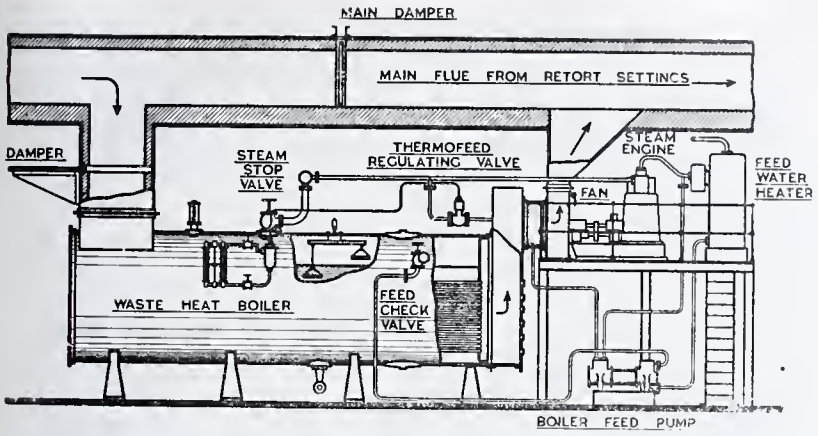


FIG. 29. GENERAL ARRANGEMENT OF WASTE HEAT FIRE TUBE BOILER—SINGLE PASS TYPE.

their installation costs to a basis which compares on equal terms with horizontal retort systems.

WASTE HEAT BOILERS

In this direction excellent progress has been made. Provision is made in practically all new retort houses for waste heat boilers, and with new continuous vertical retort plants these boilers are always fitted. A typical arrangement is shown in Fig. 29 and a type of boiler frequently used in Fig. 30.

All types of modern retort settings, though invariably provided with recuperators, mostly of efficient design, produce an exit gas of a temperature amply sufficient to warrant the installation of waste heat boilers.

With silica materials and high temperatures the exit gases are usually more than sufficient to provide the entire power required for the running of all the plant on a gas works.

The author knows of no auxiliary plant which yields so large a return on the capital outlay as a waste heat boiler properly installed. The diagram, Fig. 31,* shows the effect of waste heat recovery.

In November, 1923, Mr. J. S. Thorman, then the engineer of the Stratford works of the Gas Light & Coke Company, London, read a paper on "Waste Heat Boilers" before the Southern District Association of Gas Engineers and Managers and surprised his fellow-members

*J. W. Reber on "Waste Heat and Gas Fired Boilers," "Gas Journal," March 4, 1925.

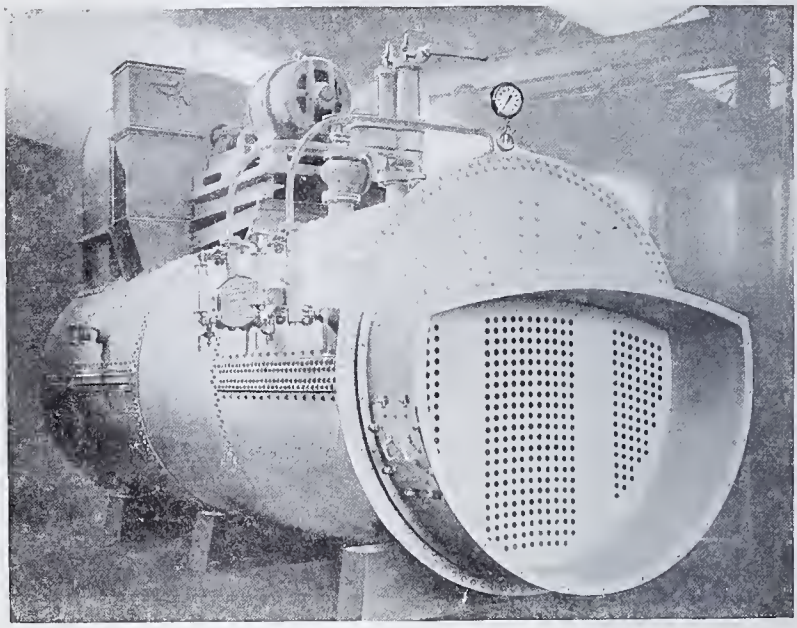


Fig. 30. Spencer-Bonecourt Kirke Patent Waste-Heat Fire-Tube Boiler. *Eight feet diameter by 21 feet long, complete with exhauster and motor. Note grouping of the tubes into three nests, between which a man can walk for the purpose of cleaning the tubes on the water side.*

The Effect of Waste Heat Recovery on Efficiency of Carbonization.

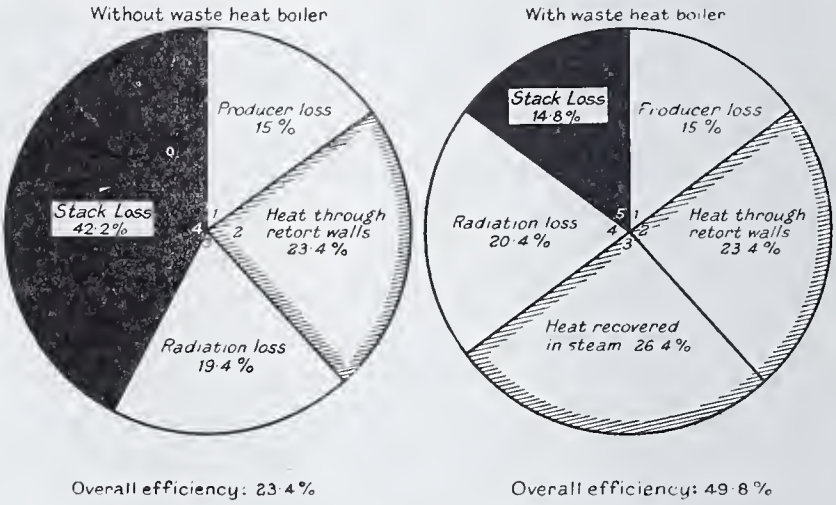

Without waste heat boiler
Producer loss 15 %
Stack Loss 42·2%
Heat through retort walls 23·4 %
Radiation loss 19·4 %
Overall efficiency: 23·4 %
With waste heat boiler
Stack Loss 14·8%
Producer loss 15 %
Radiation loss 20·4 %
Heat through retort walls 23·4 %
Heat recovered in steam 26·4 %
Overall efficiency: 49·8 %

Fig. 31. Diagram Showing Heat Distribution Per Ton of Coal Carbonized.

by stating that he was evaporating over 5 lbs. of water per lb. of coke consumed in the producers.

Considering that this was quite 75% of the duty which could be expected if the coke were burnt in a boiler for the express purpose of raising steam it did seem an extraordinarily high figure.

There were many to point out that it was a theoretically impossible result, and that there must be some serious error in the method employed of calculating the results.

Since then other works have obtained equally good figures though in the older installations the results are appreciably lower.

Mr. Thorman in his paper explained the method of maintaining the temperature of the waste gases until these entered the boiler, and showed the importance of preventing the dilution of the waste gases by air during and after the passage of the gases through the recuperators.

The installation consisted of two Kirke horizontal fire-tube waste heat boilers, each 6½ ft. diam. by 20 ft. over all in length, for a working pressure of 130 lbs. per sq. inch and a steaming capacity of 8,000 lbs. per hour.

Each boiler is fitted complete with an electric motor and fan, and feed water regulators.

The water is softened to zero hardness in a Permutit water softening plant, and is subsequently heated to 76.6° C. by exhaust steam, and then measured before use by meter.

In this case the area over which the waste gases had to travel was considerable, and after experiments it was decided to insulate the whole interior surface of the shafts and flues leading from the settings to the boilers by building an internal 3″ course of porous diatomaceous insulating brick protected on its inner side by a 3″ course of firebrick. This method reduced the calculated heat losses of 25% without insulation to 6% with insulation.

Efficient insulation is all-important.

The results obtained in a 24 hours' test at this works are set out below:

Table XV

Coal carbonized per 24 hours	254 tons
Throughput per retort	3.4 tons
Total fuel used per 24 hours (check weighed)	38.5 tons
Total fuel used per ton of coal carbonized (2½% moisture)	300 lbs.

Total fuel used per 100 lbs. of coal carbonized.....14.95 lbs.
Total fuel used per hour.....3,211 lbs.
Total water evaporated from and at 212° F. per 24 hours .....443,874 lbs.
Actual steam produced per 24 hrs. at 115 lbs. pressure 402,790 lbs.
Actual steam produced per hour at 115 lbs. pressure...16,783 lbs.
Actual steam produced per set per hour at 115 lbs. pressure .....1,678 lbs.
Actual steam produced per boiler per hour at 115 lbs. pressure .....8,391 lbs.
Actual steam produced per ton of coal carbonized at 115 lbs. pressure .....1,563 lbs.
Actual steam produced per lb. of fuel used in producers at 115 lbs. pressure (as fired, $2\frac{1}{2}\%$ moisture).....5.27 lbs.
Actual steam produced per lb. of fuel used in producers at 115 lbs. pressure (dry basis).....5.36 lbs.
Temperature of feed water.....155° F.
Power absorbed by two fans for induced draught.....36 h. p.
Equivalent of steam for power per ton of coal carbonized (calculated at 30 lbs. from and at 212° F. per h. p. hour) 91 lbs.
Steam equivalent for power for induced draught, per cent of total raised.....5.84%
Temperature of waste gases at outlet of setting.....
.....882° C. (CO_2 content 16.2%)
Temperature of waste gases at inlet of boilers.....
.....689° C. (CO_2 content 13.5%)
Drop in temperature due to dilution (by air leakage)....149.7° C.
Drop in temperature due to radiation.....43.3° C.
Heat loss between outlet of setting and inlet of boilers, due to radiation.....4.9%
Temperature of waste gases leaving the boilers.....225° C.
Tube efficiency of the boilers.....90.3%

The author has visited this works and seen the methods employed for testing and the working results over a long period, and he himself is confident that these test figures are being closely attained under ordinary working conditions.

These results are clearly materially higher than is theoretically possible, assuming that there is no extraneous source of heat to increase the waste gases.

All gas engineers know there is an interchange of coal gas and waste products of combustion between the walls of retorts, and it needs but a small percentage loss from the retorts to amount to a large percentage gain on the waste gases; also the retort gas will

contain tar, liquor in the form of steam, and the sensible heat of the gaseous mixture.

Gas engineers will often say that in their case the temperature of the waste gases is not sufficient to warrant waste heat boilers, but in such instances they are usually guided by the appearance of the exit flue, which appears black or nearly so in many cases. Though dark in color it can still measure 800-900°F. in temperature, and if the excess air admitted by leakage in the recuperator flues could be again removed, flues that appear black would show red, and measure much higher in temperature.

Many tests of the exit gases taken on the inlet to the retort house chimneys show that the CO_2 content has been reduced to less than 10%. This means that the exit gases have been diluted with 200% of excess air.

The author, when estimating the possibilities of waste heat boilers, always insists upon recuperators, flue boxes, etc., being tightened up and well clayed to prevent air leakage so far as possible before taking samples of the exit gases and their temperature entering the chimney shaft.

The relative production of steam by waste heat boilers to that required to supply all the power required by a gas works is deserving of a few words.

In the paper to which previous reference has been made Mr. Thorman stated that at the Stratford works the entire power requirements of the works amounted to:

Table XVI

Vertical Retort Plant

Lbs. of steam per ton of coal carbonized	952
Actual steam produced at 115 lbs. pressure from waste heat based upon test given	1563
Balance	611
Steam required to operate fans for waste heat boilers	91
Available for other than works purposes	520

The works in question is fitted up with complete handling plant for coal and coke, and with all the usual plant required in a modern gas works, while included in the steam requirements there is an item of 62.5 lbs. per ton of coal carbonized for steam distribution

losses, condensation, etc., while the figure of 952 includes the steam (viz. 15%) required for steaming the retorts, or 300 lbs. per ton of coal carbonized.

For the purpose of making an approximate estimate of possibilities with waste heat boilers, a diagram, Fig. 32, is here included.

In explanation of this diagram it should be stated that these figures are based upon a combination of calculated and actual results with an efficient design of fire-tube boiler, and are used to show the approximate result that can be expected under varying conditions.

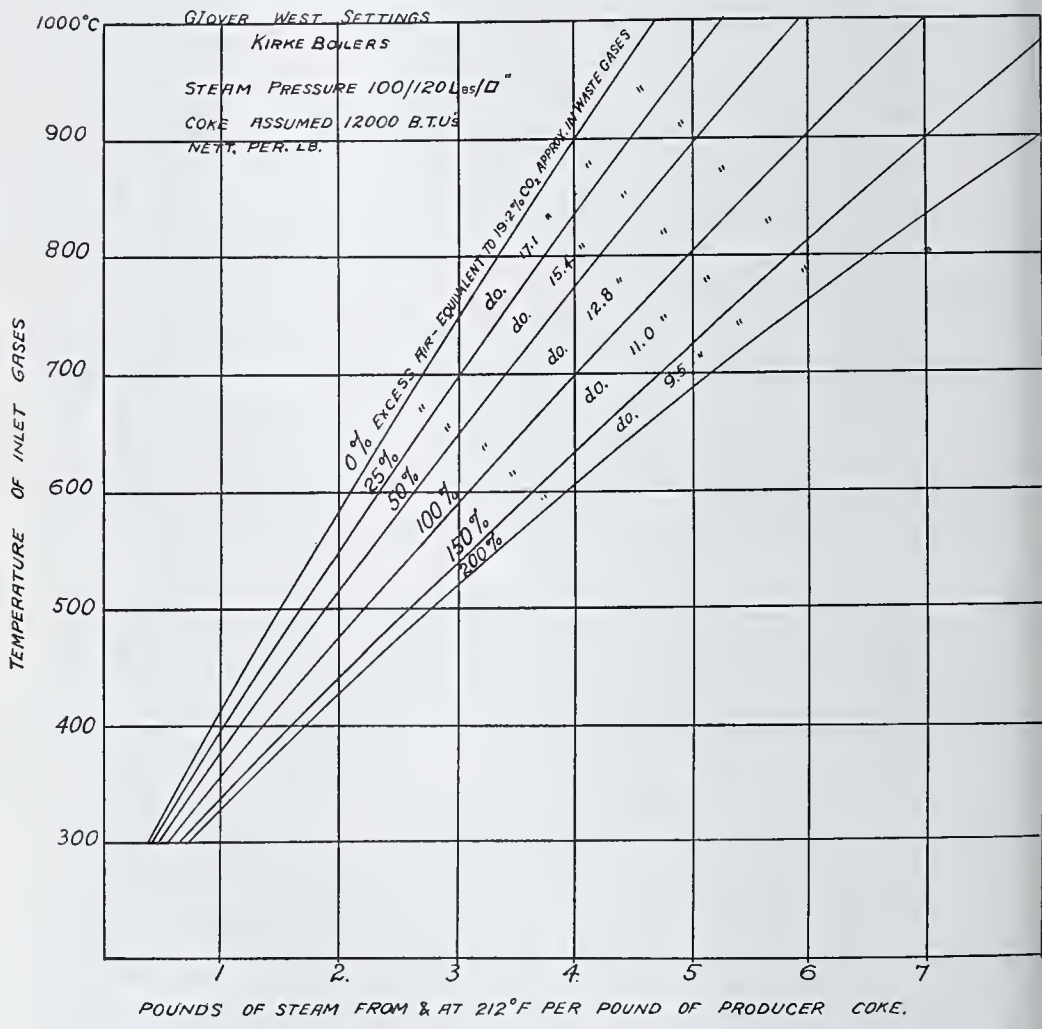


FIG. 32. GLOVER-WEST SETTINGS, KIRKE BOILERS.

It is based upon over 150 installations of waste heat boilers in English gas works.

If air is allowed to dilute the waste gases this clearly lowers the temperature at which such gases enter the boiler, and the result in steam per lb. of fuel is lower, as while the same total heat still enters the boiler a proportionately greater volume leaves the boiler, at, say, 200°C., this being at virtually the same temperature in either case.

At the same time the plant and power required for creating the necessary draught is increased in proportion to the volume of gases entering the boiler.

There is, therefore, every reason for preventing the dilution of the waste gases by air.

In England it is found in practice that the excess air in the waste gases entering the boiler varies, for the most part, from 50% to 150%, these percentages approximating to a content of 15.4% CO_2 to 11.0% CO_2 respectively.

The large proportion of excess air appears to be very high, and it shows the scope which exists for improving the brickwork and the recuperators at the points where air can dilute the waste gases.

The author mentions elsewhere in this paper that there is a tendency to dispense entirely with the recuperators in retort settings and to replace these by waste heat boilers, but to do this an outlet for the excess steam is required, and this is not evident under existing conditions. The most suitable outlet would be for the purpose of generating electricity, and this is discussed briefly at the end of this paper.

There is no question whatever that waste heat boilers, where efficiently installed and properly operated, are justifying their adoption in a remarkable manner.

Refractory Materials for Gas Works

The question of refractory materials is a matter of vital importance in many industries.

It has been rightly said that during the War the limiting factor in the production of munitions was the rate of production and application of refractory materials for the building and maintenance of furnaces for the metallurgical, glass and ceramic industries.

In fact, during the War it was impossible to purchase silica bricks

in England except for purposes of vital importance. The steel industry required the whole production. Gas works were mostly using fireclay and siliceous materials, and had to be content with material having a content of less than 90% silica.

This is partly the reason that in England the use of 95% silica for retort settings has not yet been developed to the same extent as in the United States, the other reason being that England is blessed with excellent raw fireclay, which has either been used as the main raw material for making firebricks and retorts, or has been mixed with a proportion of silica to increase its refractoriness under load conditions.

Classification of Refractories

It should here be explained that the terms, "fireclay," "siliceous" and "silica" refer to materials containing the following percentages of silica, as laid down in the Standard Specification for Refractory Materials for Gas Works by the Institution of Gas Engineers in England. "Fireclay" refers to "goods made from fireclay containing approximately not more than 75% of silica." "Siliceous" refers to material "containing from 80 to 92% of silica." "Silica" refers to that "containing 92% and upwards of silica."

The specification leaves open the description of material containing from 75 to 80% of silica, but it adds a note that goods made from fireclays containing as much as 80% silica shall be considered to conform to the fireclay specification if they pass the tests specified.

Present Practice in England

The position at present is that silica is invariably adopted for the supporting walls of retort settings in and around the combustion chamber zone, while silica is usually adopted for new retorts.

When the retorts are of silica it is the general rule to construct the entire supporting walls also of silica.

Composite settings partly of silica and partly of siliceous and fireclay are being used to a considerable extent. In this type of construction in which the retorts are of good fireclay or siliceous material, it is realized that the internal temperature of the retorts is about 250° C. below the outside temperature in the combustion chamber zone, and thus with a combustion chamber temperature of 1400° C. the average temperature of the retort itself is only 1275° C.

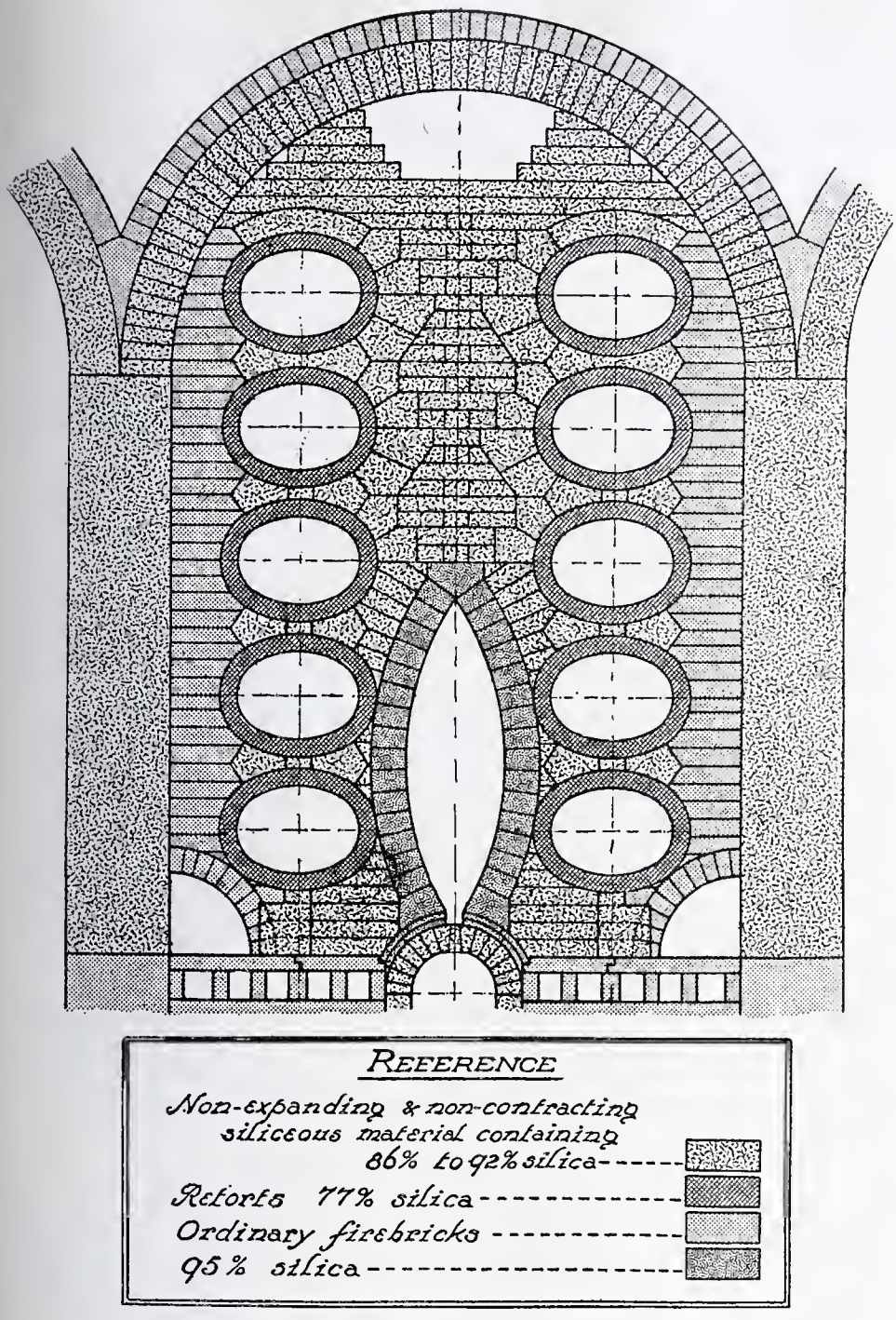


FIG. 33. RETORT SETTINGS USED BY THE SOUTH METROPOLITAN GAS COMPANY, LONDON.

Consequently, the retort material itself, being protected by the comparatively low internal temperature, is enabled to withstand ordinary working conditions over a long period.

It is found in practice that certain high-class fireclay moulded retorts, with silica contents of, say, 74% to 80%, are capable of giving excellent service with combustion chamber temperatures averaging 1400° C.; but in these cases it is essential that the retorts are well supported in their original position throughout their length by cross walls of the most refractory silica materials.

The South Metropolitan Gas Company (London) use a composite horizontal retort setting shown in Fig. 33, comprising moulded retorts of 77% silica, supported by cross walls of nonexpanding and noncontracting highly siliceous material having a silica content of 89 to 91% silica, and combustion chamber arches of 95% silica. All the material is the best of its class, and the Company's inspector is retained permanently at the maker's works to inspect not only the finished material, but also the material during the process of manufacture.

This company has in use upwards of 18 miles of retorts—mostly horizontal—and as a result of the type of setting and materials used, and of careful operation, average lives of retorts are made to exceed 2,000 working days, although this company has no water gas plant and has to meet peak loads by heating up and cooling down settings to an extent much greater than other undertakings having water gas plant, as is the case with the great majority of large gas undertakings in England.

In the case of the settings just described, it is probable that the temperatures in the combustion chamber are not maintained at an average above 1320° C., to provide a good margin of safety.

Properties of Materials Used

In an excellent paper read by Mr. W. T. Gardner, of the Woodall-Duckham Company, before the Ceramic Society in 1926, there was included a table setting out the more important properties of good quality refractory materials, as supplied in England. Mr. Gardner has been responsible for the testing of all kinds of refractories used in the Woodall-Duckham retorts, and can speak with authority on the question.

Table XVII

APPROXIMATE AVERAGES

	FIRECLAY	SILICEOUS	SILICA
Ordinary refractoriness without load.	Cone 29 = 1650° C. to Cone 30 = 1670° C.	Cone 29 = 1650° C.	Cone 30 = 1670° C. to Cone 31 = 1690° C.
Refractoriness under load of 50 lbs. per sq. in.....	1325° C.	1400° C.	1600° C.
After contraction or expansion—2 hours at 1410° C.....	Contraction 0.5 to 1.0 p.ct.	Expansion 0.2 to 0.5 p.ct.	Expansion 0 to 0.5 p.ct
Porosity.....	18 to 30 p.ct.	34 to 37 p.ct.	25 to 35 p.ct.
Apparent specific gravity.....	1.9 to 2.1	1.6 to 1.63	1.6 to 1.7
True specific gravity	2.6 to 2.7	2:45 to 2.55	2.33 to 2.40
Linear expansion p.ct. 15° C. to 1000° C.	0.5 to 0.6 p.ct.	0.7 to 0.8 p.ct.	1.0 to 1.25 p.ct.

To comment briefly on the above table: Mr. Gardner in his paper refers to fireclay bricks "usually containing from 55 to 70% silica," siliceous "usually from 80 to 90% of silica," and silica from "93 to 96," and presumably the above table is intendeded to refer to the three classes of materials containing the above perecentages of silica.

It leaves open the class of refractory materials containing from 70 to 80% if silica, this being sometimes of natural clay and sometimes of mixtures of fireclay and silica.

Now it is this class from which the retorts in the composite settings, above briefly described, are made, and there is every reason to think that this material in practice behaves like the siliceous material included in Mr. Gardner's table. This the author considers is another reason that the composite settings mentioned above will often give excellent service at high combustion chamber temperatures.

Silica Retorts

Silica retorts are, however, being very largely used in England. Vertical retorts are now built of silica for a considerable part of

their length, i. e., about 14 feet for a retort of 26 feet in length, and this is built between the top zone, where the coal is receiving its preliminary carbonization, and the bottom zone where the coke is being steamed.

The West Company use for the hottest zone bricks of their own manufacture containing about 91% silica, burnt at a temperature of 1500°C. for a soaking period of 24 hours, and showing an after-expansion of 0.01%.

This class of material, of which the author has used a large quantity, has to a large extent the good qualities of both siliceous and silica materials, without the disadvantages of either, and can therefore be used with advantage for retorts, supporting walls, and flues with very high temperatures, yet without necessitating allowances for expansion by means of wood, millboard, and the leaving of spaces.

Mr. W. Emery, in a very interesting paper read in 1924 before the Institution of Gas Engineers, quoted from some information supplied by the Woodall-Duckham Company, who probably have as good a practical knowledge of refractories as any organization in England.

This was to the effect that a 26-ft. retort—14 feet of which is silica—expands approximately 3¼ inches at a temperature of 1400°C. and in 3 months' working increases to 3½ inches. This indicates, it is stated, that the silica expands 1.4 per cent for the 3½-inch rise (probably comprising 1.2 per cent reversible and 0.2 per cent permanent) plus a further 0.1 per cent permanent, making a final total of 1.5% for the 3½-inch rise. They further stated that 70 to 75% of the total expansion of silica settings takes place during the warming up stages and before any color is visible in the combustion chamber.

This latter point is a matter of great importance and emphasizes the care which should be taken to watch the preliminary stages of heating up all classes of silica settings.

As Gardner states—"In warming up silica retort settings it is essential that the utmost care should be taken to raise the temperature very slowly and evenly up to 300°C., during which range of temperature approximately 60 to 65% of the full expansion takes place. This high expansion is due to the considerable increase in volume which occurs at approximately 250°C., resulting from the inversion of

alpha-christobalite to beta-christobalite. A further rapid expansion also takes place at 575°C. at which temperature the alpha variety of quartz is inverted to the beta form. It is therefore necessary to continue to raise the temperature slowly and evenly until after the quartz inversion has been completed—say 600°C.—by which time upwards of 90% of the full thermal expansion will have taken place."

Expansion Allowances in Horizontal Settings

With horizontal retort settings allowances for expansion of silica are made by the methods shown in Figs. 34, 35 and also in Fig. 11.

In explanation of Fig. 34, Mr. C. H. Rutter, the engineer of the Portslade Works of the Brighton Gas Company, writes in the Gas Journal, Ocotber 20, 1926:

"It must be remebered that there are two distinct expansions—(a) the reversible thermal expansion of approximately ⅛" to 1 foot, which is common to all silica; and (b) the after expansion which varies with every manufacturer's material, dependent as it is on the firing temperature in the kiln. In experiments made at Portslade, the latter variation has been between somewhat under 1/32" to nearly ¼" per foot; and this amount has to be added to the ⅛" reversible expansion. It is well to subject all silica material to physical and refractory tests, the results of which determine the amount of expansion for which allowance must be made. In the all-silica settings at Portslade an allowance of ⅛" per foot is made for the reversible thermal expansion, and 1/16" for the permanent expansion, making, in all, 3/16" to 1 foot, because this figure was found to correspond as nearly as possible to the expansion ascertained by actual experiment on the particular brand of silica used.

"From the drawing it will be seen that the setting, which is 9 ft. wide, requires an allowance of 9 by 3/16 inches=27/16" for the lateral expansion; so two layers of S.X. board each ¼" thick are placed at each end of the crosswalls, and the balance of 11/16" is made up by dry vertical joints between the bricks in the center of the crosswalls. In the vertical height there is approximately the same

Vertical Joints in Centre
of Cross Walls left dry
Two ¼" Pieces
of "SX" Board
with ¼" Joint making a
total of ¾" at the top
Two ¼" Pieces of "SX" Board
placed at each side as
shown making ½"

FIG. 34. THE BRIGHTON AND HOVE GAS COMPANY'S SETTING SHOWING ALLOWANCES FOR SILICA EXPANSION.

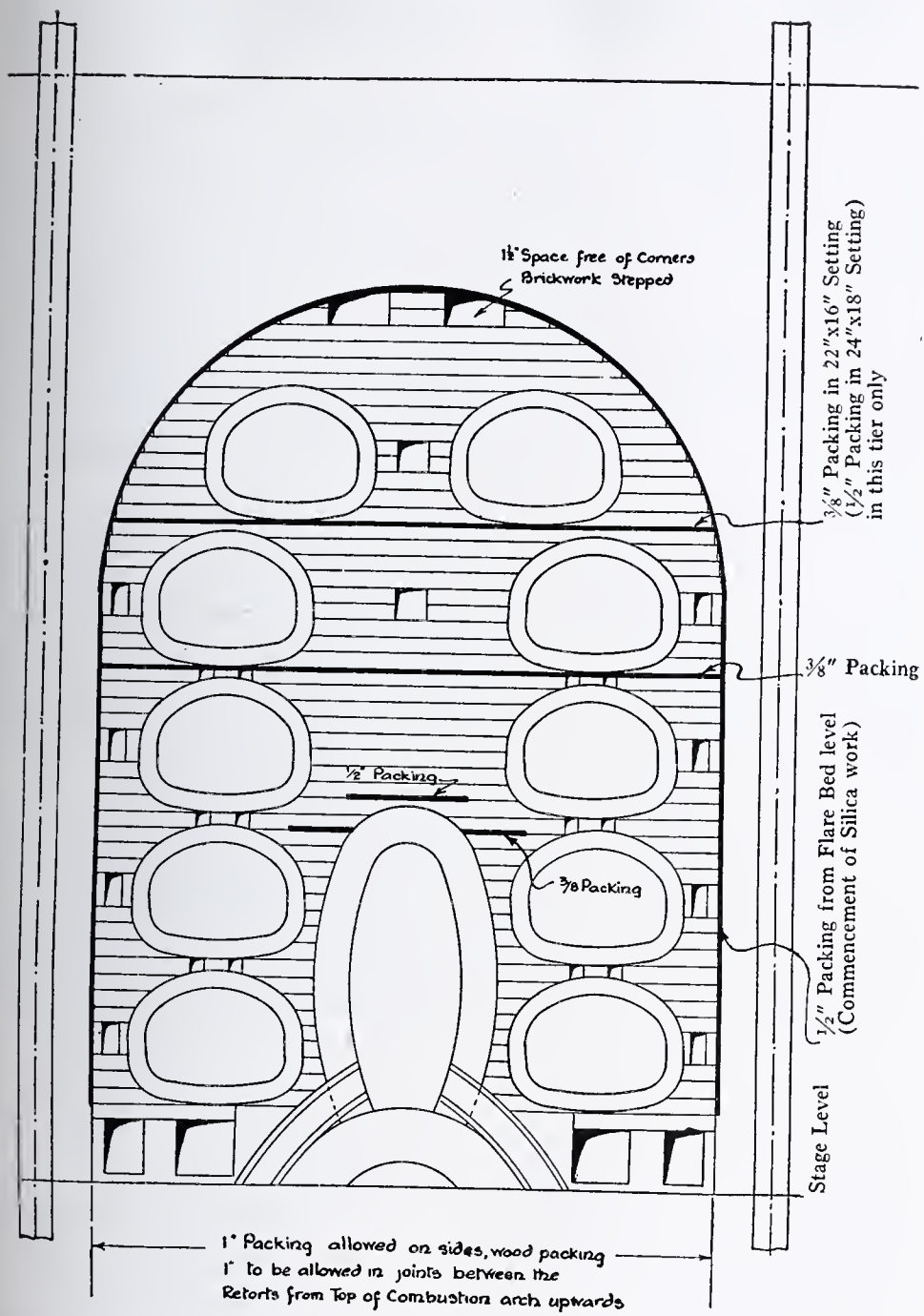

1½" Space free of Corners
Brickwork Stepped
⅜" Packing in 22"x16" Setting
(½" Packing in 24"x18" Setting)
in this tier only
⅜" Packing
½" Packing
⅜ Packing
½" Packing from Flare Bed level
(Commencement of Silica work)
Stage Level
1" Packing allowed on sides, wood packing
1" to be allowed in joints between the
Retorts from Top of Combustion arch upwards

FIG. 35. BECKTON STANDARD SETTING, SHOWING ALLOWANCES FOR EXPANSION.

expansion to be provided, ¾" of which is taken at the top and the remainder in thick joints under, and linable with, the retorts."

After-Expansion and Specific Gravity

Considerable improvement will be possible when silica bricks can be generally supplied with guarantees of after-expansions so small as to be virtually ignored in the design, building and operation of retort settings.

It is the general opinion in England that silica bricks are showing a steady improvement in quality. Gardner states that "several firms are supplying silica bricks having an average specific gravity of 2.34 and giving an after-expansion result at 1500° C. not exceeding an average of 0.2%."

Mr. A. H. Middleton, of the Consett Iron Company, who has studied silica brick manufacture in the United States, and who is a large maker and user of silica bricks in coke ovens, states that "he would not advise the use of brick with a higher specific gravity than 2.35 if it is to be used for ovens which are to be worked at very high temperatures."

The reason of this is that in burning silica bricks the raw material, viz. quartzite or ganister rock, having a specific gravity of 2.650, is, or should be, converted to cristobalite having a specific gravity of 2.333 and tridymite with sp. gr. of 2.270. The higher the temperature and the longer it is continued, the larger the brick will become and the more complete will be the conversion, and the lower will be the specific gravity of the final product.

Consequently specific gravity tests have been established as being highly important in this connection.

As Mr. W. S. Rees, Lecturer on Refractories, University of Sheffield, states: "It should be possible for a manufacturer of silica bricks to prepare from experimental data a chart on which the after-expansion could be read off from a determination of the true specific gravity."

There is, of course, a practical and economic limit beyond which it is not possible to extend the firing of the bricks, and as a consequence

it often happens that growth in size which should have taken place in the kiln takes place in the retort setting or oven.

Silica and Its Effect on Retort Output

It is generally conceded that with silica retorts there is a very noticeable increase in conductivity as compared with fireclay retorts at high temperatures. Leech states that at Beckton the difference between the inside and outside temperatures of a fireclay retort will be 260° C. as compared with 200° C. in the case of a silica retort.

In practice this advantage appears to result in a greater throughput of coal than would at first sight be considered possible, and further it has been established that small percentage increases in combustion chamber temperatures result in large percentage increases in the quantity of coal carbonization in a given time.

The author has found in practical working that by increasing combustion chamber temperatures 10% he has been able to increase the quantity of coal carbonized by 50%.

Middleton reports some experiments in which by increasing temperatures by 17½% an extra throughput of 54 per cent of coal was obtained.

It follows that higher temperatures must be of interest to progressive gas engineers, the advantages being so attractive, and in fact it is one of the directions in which it has been and will continue to be possible to reduce the capital costs of carbonizing plant.

Increased throughput is a very potent way of bringing about this desirable result, and in this connection no subject is of more importance than the proper use of good and suitable refractory materials.

Jointing Cement

In connection with silica work generally a subject of great importance is that of the jointing cement used.

The cement must be highly refractory, non-contracting, chemically inert at working temperatures, and capable of maintaining good gas-tight joints, while at the same time it must have good adhesive and plastic properties.

It is generally agreed that the more nearly alike in chemical composition and physical behaviour are the cement and the bricks with which it is to be used, the more satisfactory will be the result. To ful-

fill such requirements the cement must contain the maximum of silica and the minimum of clay. The cement when dried must have sufficient mechanical strength to enable the structure to bear its own weight previous to the first firing.

Mr. W. Emery carried out some tests with varying mixtures and reported that of the 26 mixtures tried, one containing 1 part of clay (a fat, plastic ball clay), 7 of ganister, 2 of grog, made an excellent cement and gave the best result when tested under load of 50 lbs. per sq. inch at cone 16. A good result was also reported when the ball clay was replaced by a highly-plastic refractory clay. It will be noticed that in each case the clay proportion amounted to 10% of the mixture.

It is usually found necessary to take stringent measures to prevent bricklayers from mixing up their own jointing cement, this having been the cause of many failures.

Excellent co-operation is now, and has been for some years taking place in England between the universities, which have done some exceptionally good work on the research side of refractory materials, and the manufacturers and users, and this has resulted in good progress being made.

Complete Gasification Plant

Of this type there are some 200 examples in English gas works. With few exceptions, these are of the Tully type, and are mostly small in capacity, making less than ½ million cubic feet per day.

There are, however, several units at work making from ½ to 1 million cubic feet per day. It should be explained that there is no reason whatever to prevent the adoption of large units.

The Tully process has for its object the carbonization of the coal to coal gas and the conversion of the resulting coke to water gas in the one apparatus, the coal being first carbonized in a vertical retort externally heated by the blow gas, and internally heated by the water gas during "Up Runs." Fig. 36 shows a section of the plant.

The design provides for the better utilization of the heat contained in the hot blow gases and in the water gas itself, while the passage of the latter gas through the retort has advantages apart altogether from the value of its sensible heat. This has, in fact, been demonstrated as the result of steaming vertical retorts.

The cycle used in the water gas section of the plant is the same as ordinarily employed in a water gas plant.

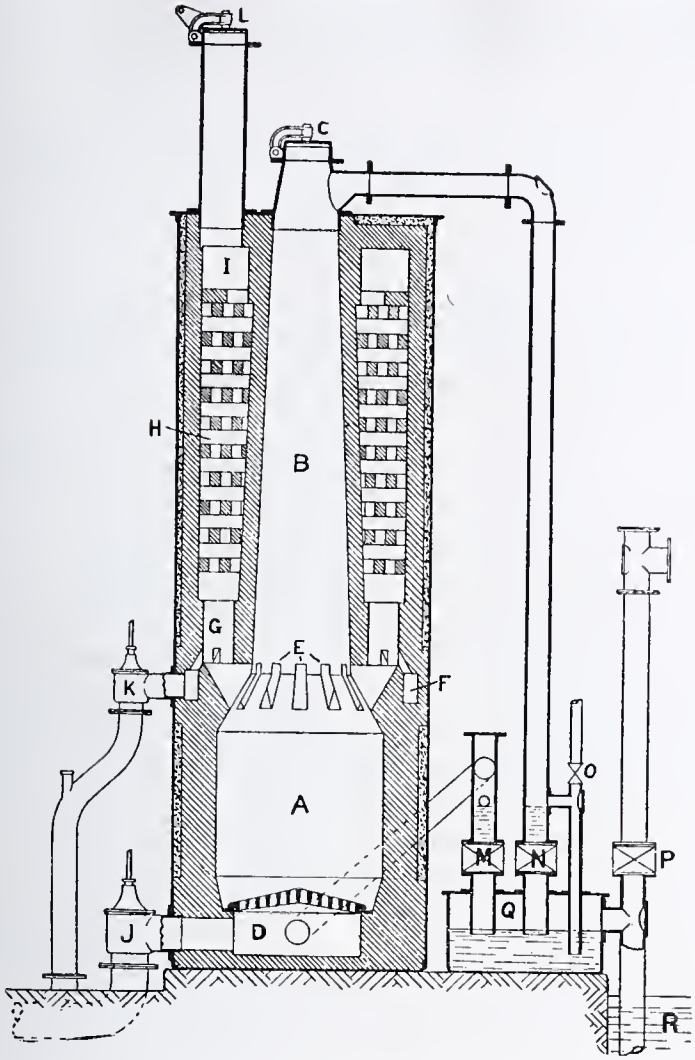


FIG. 36. THE TULLY SYSTEM OF COMPLETE GASIFICATION.

This Plant is designed for the production of 350 B.t.u. Gas from Coal, or 300 B.t.u. Gas from Coke.

A—Water Gas Producer.
B—Vertical Retort.
C—Coal Charging Door.
D—Ash Pit.
E—Blow Gas Nostrils.
F—Secondary Air Belt.
G—Blow Gas Combustion Chamber.
H—Checker Brickwork.
I—Equalizing Chamber.
J—Primary Air Valve.
K—Secondary Air Valve.
L—Waste Gas Stack Valve.
M—Down Run Gas Valve.
N—Up Run Gas Valve.
O—Coal Gas Bye-pass.
P—Gas Outlet Valve.
Q—Hydraulic Valve Box.
R—Tar and Liquor Sump.

The vertical retort and its charge of coal uses a large part of the considerable amount of heat which passes away from a water gas generator.

The proportioning of size of the retort to the generator needs to be such that a proper coke is fed from the retort to the generator, and that ashes of reasonable freedom from combustible matter are produced at the base of the generator.

A considerable variety of coals can be used satisfactorily. Non-coking coals of high volatile content are very suitable, as are nuts and coarse coal of coking varieties; but swelling coals with considerable percentage of "fines" are troublesome.

Coke can also be used alone or as a mixture with coal, and this is frequently done.

Gas can be made, given a suitable coal, as high as 400 B.t.u. per cubic foot, but in practice it is found that a higher thermal value is obtained by making a gas of 350 B.t.u.

The yield of gas with plants in regular operation varies from 40,000 to 53,000 cubic feet per ton, depending upon the class of coal used and the efficiency of operation.

Total thermal yields of gas amounting to 156 to 170 therms per ton of good coal are readily obtainable with proper operation, while in addition there is a yield of 12 gallons of tar per ton.

With small plants worked from 8 to 12 hours a day only and closed down temporarily for the night, as is the case with so many of these plants, the results are obviously much affected, and in these cases the make per ton will vary from 26,000 to 35,000 cubic feet.

A typical analysis of the gas is shown below:

CO_2	5.8%	
C_nH_m	0.8%	
O_2	1.0%	
CO	32.4%	
H_2	44.0%	
CH_4	7.2%	
N_2	8.8%	100.0

A number of Tully plants are running on the Continent with mechanical grates, automatic operation of valves, and waste heat boilers, and with, it is reported, very good results. In the author's opinion there is no question that a plant of any size should have all these modern auxiliaries. The Tully plant, as is the case with water gas, needs

a short cycle to obtain the best results, and this needs a machine, while the advantages of mechanical grates need no boosting. On the Continent there are 6 Tully plants with automatic operation of valves, 3 with mechanical grates and 7 with waste heat boilers.

In England there are many Tully plants, but none is fitted with the above labor and fuel saving devices.

The author considers that this type of plant should prove suitable for gasifying the type of coal now being used in water gas generators in the United States, and a comparison of results would assuredly prove most interesting.

The Continuous Vertical Retort as a Complete Gasification Plant

Under the heading of complete gasification the author would briefly refer to the possibility of using a continuous vertical retort for making such a gas.

An interesting series of tests have been carried out in England during 1925 at the West Company's experimental vertical retort plant, and are here included in Tables XVIII and XIX.

Table XVIII

Coal Wigan Arley Nuts: Ash 8%: Moisture 3%: V.C.M. 33%

TEST	Gas made per retort per 24 hrs. cu. ft.	Coal carbonized per retort per 24 hrs.	Make per ton cu. ft.	Therms	Average cal. value	Coke discharged in lbs. per ton of coal
A	96,730	6.38 tons	15,160	76.2	503	1345
B	96,650	5.66 tons	17,070	80.6	472	1336
C	106,475	5.28 tons	20,170	89.8	445	1243
D	106,800	4.37 tons	24,440	103.4	423	1204
E	101,660	3.75 tons	27,110	108.7	401	1183
F	99,750	2.58 tons	38,660	144.5	373	1145
G	98,380	2.07 tons	47,530	171.0	360	1096

The analyses of gas produced in these series of tests are here summarized:

Table XIX

Test No.	A	B	C	D	E	F	G
CO_2	1.4	1.2	2.7	3.2	4.3	5.0	4.0
O_2	0.2	0.1	0.2	0.2	0.6	0.3	0.2
C_nH_m	2.3	2.3	2.2	2.1	1.6	1.3	1.2
CO	13.0	14.1	20.5	21.6	25.2	28.9	31.2
CH_4	22.6	18.6	15.6	13.3	11.8	8.9	7.9
H_2 (by diff.)	55.0	57.1	53.4	53.6	53.0	50.5	48.2
N_2	5.5	6.6	5.4	6.0	3.5	5.1	7.3
Cal. val. (av. of all tests during collection of samples).	503	472	445	421	401	373	360
Specific Gravity (Calculated: air = 1.0)	0.389	0.385	0.439	0.460	0.527	0.506	0.525

To comment briefly on these results, it will be seen that something like the full quantity of gas expected from complete gasification is produced in this plant, but in addition there is also a yield of upwards of 25 gallons of tar, and of upwards of 20 lbs. of sulphate of ammonia per ton of coal carbonized.

All the coke discharged from the retort, i. e., 1096 lbs. per ton of coal carbonized, when making a gas of 360 B.t.u. (gross) would be required as producer fuel and for generating steam, and this is, therefore, the limit beyond which it would not be economically advisable to steam the charge further.

These tests are particularly interesting as showing the wide range of gas quality which can be made in the continuous vertical retort.

Low Temperature Carbonization

The author does not propose to deal with this question, as so far it has found no place in ordinary English gas works practice, though practical experiments have been and are being made.

He has little doubt, however, that one or more processes of this system will be adopted in the future, as the type of fuel produced is badly required for the English open grate.

This subject is forming part of Dr. C. H. Lander's paper, and

it is therefore unnecessary to deal with a subject in which Dr. Lander is a recognized authority.

Future Developments

The future of the coal carbonizing industries is full of most interesting possibilities, of which people outside these industries have no conception. Important and recent developments in England have already been referred to, but in other countries striking progress is being made.

The development of the coke oven and gas oven in the United States has always impressed the author as being wonderfully successful. However, the development which, to the author appears overdue, is that which would enable the production of gas and electricity to proceed on economical lines side by side in the same works. The possibilities in this direction have never been demonstrated.

Reference has already been made to the surplus steam available from waste heat boiler plant in gas works. In addition to this there is the steam which could be generated from the coke breeze produced for the purpose in question. For the moment it will be assumed that all the coke other than that required for carbonizing the coal will be sold and that surplus waste heat and breeze will be available for generating electricity.

It is assumed that:

(1) The gas works requirements of steam for all power and other purposes will be 805 lbs. per ton of coal carbonized; and that 1340 lbs. of steam will be generated from the waste heat, having a surplus of 600 lbs. steam per ton of coal carbonized.

(2) The breeze produced under ½ inch will be 118 lbs. per ton of coal carbonized, and that it will generate 5 lbs. of steam per lb. of fuel.

(3) 20 lbs. steam will be used per K.W. Hr. Then, the surplus power produced on a gas works using 1000 tons a day will be:

		Lbs. steam available
Waste heat	1,000×535 =	535,000
Breeze	1,000×118×5=	590,000
Total		1,125,000

which at 20 lbs. per K. W. Hr. is equivalent to 56,250 K. W. hours, or 56.2 K. W hours per ton of coal carbonized

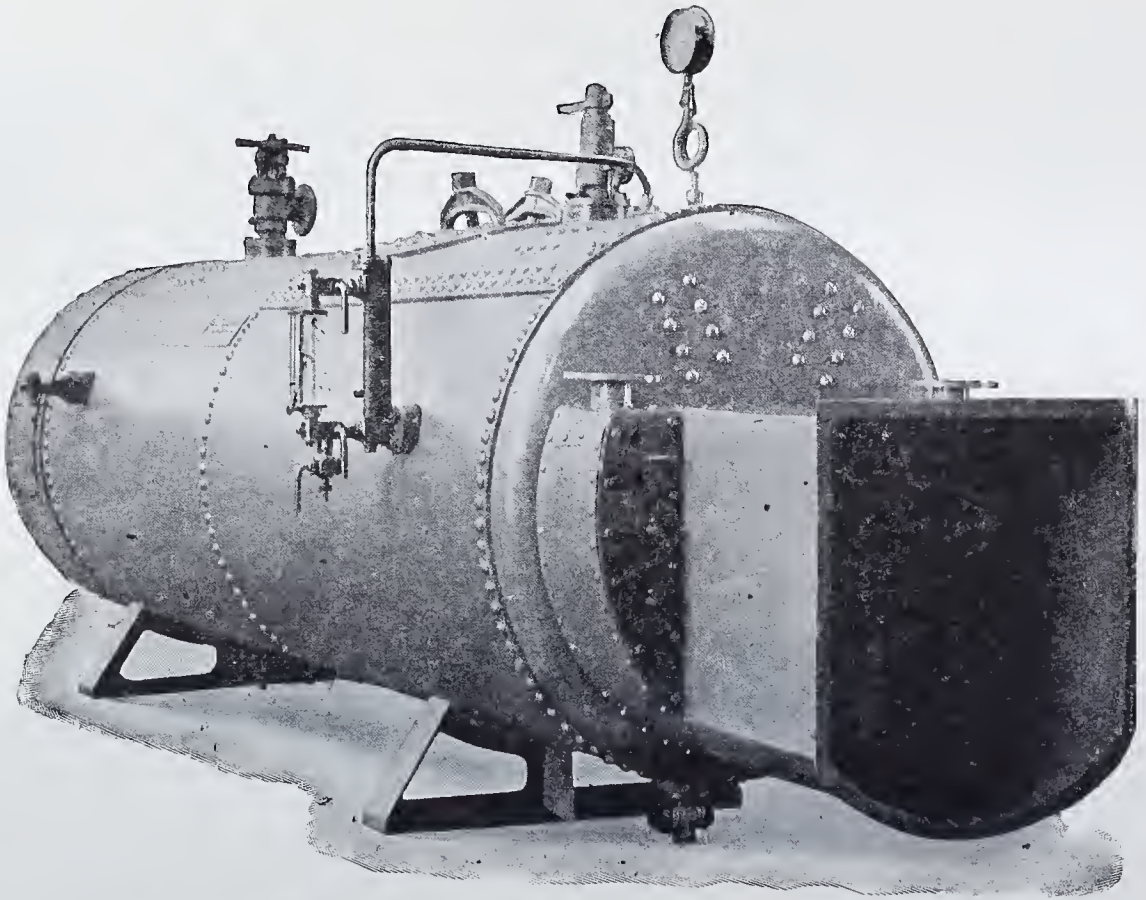


FIG. 37. SPENCER-BONECOURT KIRKE PATENT COMBINED WASTE-HEAT AND GAS-FIRED BOILER.

The central group of tubes are for generation of steam from hot waste products of combustion and those at the sides for firing with gaseous fuel.

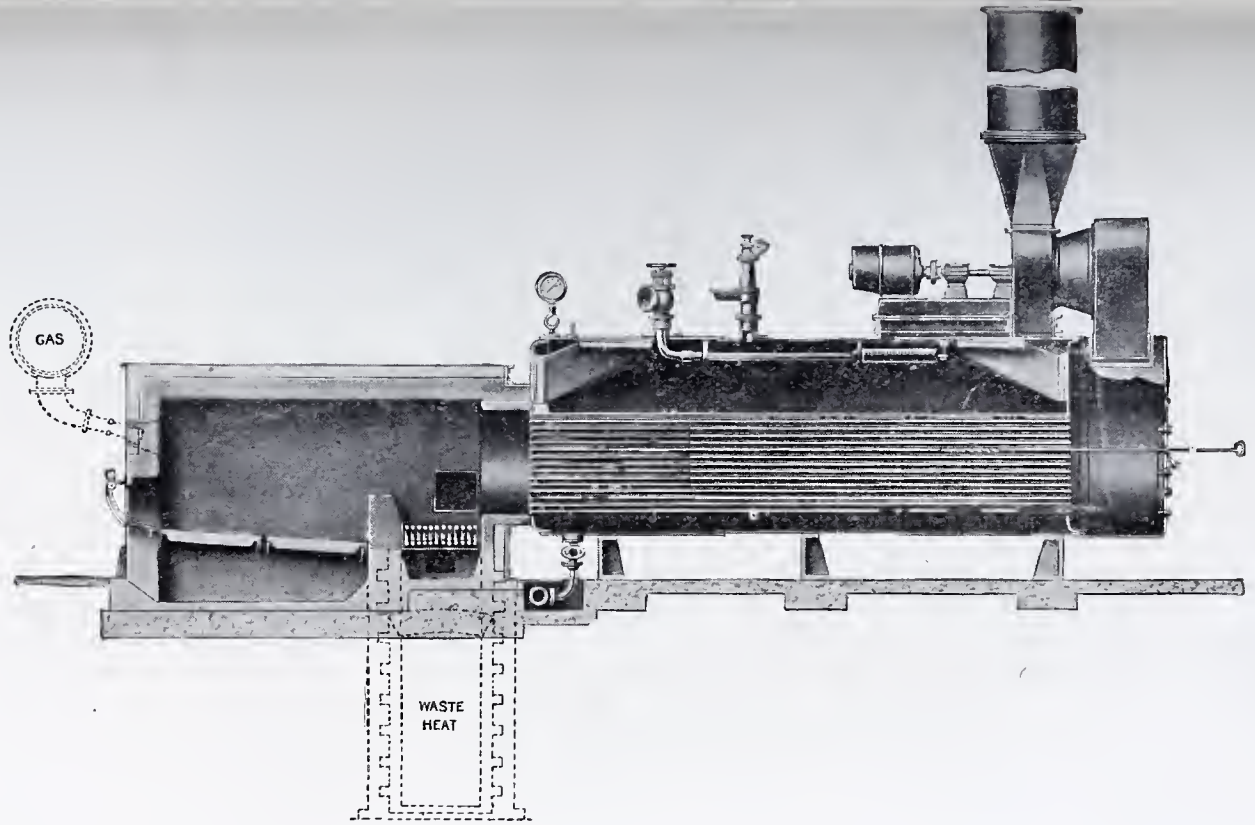


FIG. 38. SECTION OF SPENCER-BONECOURT KIRKE PATENT FIRE-TUBE BOILER WITH SUPERHEATER.

Arranged for simultaneous or alternative firing with coal, waste heat, or gaseous fuel. The Patent Superheater, which may be armoured if desired, is arranged out of the path of gases that have a high temperature, and is heated from the combustion chamber walls by radiation, or by contact with waste gases at a low temperature discharged from an Industrial Furnace, or by both. The tube ends are beaded over, and, if desired, may be armoured with suitable ferrules.

It should be pointed out that the steam produced by waste heat would be substantially uniform in amount throughout the 24 hours, but that from the breeze could be varied as desired to meet the changing loads.

For this purpose waste heat boilers are made to operate on either gaseous or solid fuel, or a combination of both as shown in Fig. 37. Alternatively these boilers are fitted up to take the waste gases in one section of the boiler and to be fired by gaseous fuel in another section of the same boiler, as shown in Fig. 38. These types of boilers would render the scheme outlined above the more easy of accomplishment. Further flexibility could be provided by the use of steam accumulators, whereby the steam from waste heat could be stored until required for electricity generating or other purpose.

The distillation of tar and the evaporation of ammoniacal liquor should also find a place in such a scheme and it should be possible to utilize the waste heat and the live and exhaust steam produced therefrom for such purposes.

The advantages of combining the production of gas and electricity in one works are not confined to fuel and its economical utilization. The combined use of certain of the personnel, workshops, laboratory, stores, offices, workmen's accommodation, transport facilities, water supply, lighting and heating arrangements, and so on, would have advantages of considerable value both in the expenditure of capital and in operating costs.

In conclusion the author would express his indebtedness to the many friends who have supplied him with illustrations and data from which much of the information contained in this paper has been compiled.

DISCUSSION

Arthur D. Little.* It has been a high privilege to listen to so significant and suggestive a paper as that of Dr. Fischer, but the first thought which it suggests is one peculiarly disturbing to our national complacency. While our technical colleagues in Germany, France, and England are striving through research, splendidly supported by government and industry, to impress a higher form value upon the fuel energy of coal, we in this country have been prodigally wasteful of

*Consulting Engineer, Cambridge, Mass.

these very form values which others are so earnestly endeavoring to create. We recognize, in the production by Dr. Fischer of a few hundred grams of hydrocarbons, a technical triumph of the most far reaching significance, but what shall we say of our own improvidence? We have wasted a large proportion of our once vast petroleum resources, with the result that the total present reserves of oil available in proven sands are estimated at about 4½ billion barrels, or but six years' supply, at our present rate of production. Equally deplorable has been our waste of natural gas. It has been estimated that at one period, in the Cushing field in Oklahoma alone, more than 100 billion cubic feet of natural gas was blown into the air in the course of a single year. This is the equivalent in use of 5½ million tons of coal.

Our present production of petroleum is something over 750 million barrels and reached, on the 26th of last October, the stupendous 24-hour figure of 2,368,000 barrels. The magnitude of these numbers naturally leads one to inquire what new demands upon our coal supply would be created were we to find ourselves under the necessity of turning to the Fischer process for an equal amount of oil.

Dr. Fischer's yield of 100 grams of hydrocarbons per cubic meter of water gas indicates that about 1,600 pounds of coal would be required to yield one barrel of oil. We should therefore be called upon to provide for this new purpose alone an amount of coal approximately equal to the entire present product of our coal-mining operations. It is also significant in its bearing upon the economic aspect of the process in this country that we still have, untouched, almost unlimited reserves of oil shale, from which the yield of oil per ton generally approximates and often greatly exceeds the yield which the Fischer process promises to give from coal.

Dr. Fischer's demonstration that high pressures and temperatures are not required for his synthesis must be regarded as an important technical advance, but he is still under the necessity, which is common to substantially all catalytic processes, of such thorough purification of the reacting mixture as shall preclude the poisoning of the catalyst. Dr. Fischer states, however, that he has solved the problem of the purification of technical gases in a simple manner. In view of the considerable cost of the comparatively incomplete purification of water gas in this country it would be helpful if Dr. Fischer would give us the general figure covering the cost of purification by his new methods, since we may assume that these must remove not only sulphur present as hydrogen sulphide, but also the so-called organic sulphur, which is far more difficult of removal.

Whatever conclusions may be reached as to the immediate economic status of the Fischer process, the fact stands clearly out that Dr. Fischer by these brilliant investigations has opened a new chapter in the chemistry of a compound so fundamental, simple, and supposedly well known

as carbon monoxide, and the impact and influence of these discoveries upon both organic chemistry and the technology of fuels is bound to be far reaching and profound.

In considering Mr. Gill's masterly and comprehensive exposition of the present status of the gas industry in England one cannot but regret that William Murdock, the father of the gas industry, could not know how far that little gas burner in his dwelling was to throw its beams. Here, in the United States, alone there were sold last year 422 trillions of cubic feet of manufactured gas, whereas only 112 trillions, if one can apply the word "only" to figures of such astronomical dimensions, were sold here in 1905, an increase of 376% in twenty years. In five recent years the city of Baltimore consumed more gas than during the preceding century.

In spite of this amazing expansion, we are confronted on every side by evidence that the gas industry is entering upon an era of still more intensive development. Having learned to cook by gas, we are now about to install the gas-fired refrigerator. There is a very definite trend toward house heating by gas, while of still greater significance is the rapidly extending industrial use of gas. From the gas-fired refrigerator it is but a step to refrigerated motor trucks and freight cars carrying their supply of gas compressed in cylinders. House heating by gas, in any general way, will call for new and very heavy capital expenditures, but the chief present obstacle to such general introduction is the idle equipment problem of the summer season. It may be that Professor Fischer has pointed out the way to its solution through the conversion of water gas to motor fuel or that the combination of alcoholic synthesis with the gas industry, as suggested yesterday by General Patart, may provide the necessary seasonal load. However this may be, there is no question in my mind that the gas industry is on the eve of a tranformation, in the course of which its activities will assume a more distinctly chemical aspect.

Mr. Gill has emphasized the important influence upon the industry in Britain of the adoption of the therm as the unit of sale. We are still, in the United States, laboring under the disadvantage of a diversity of standards which are themselves subject to constant change. The tendency is toward a lower B.t.u. requirement, largely because it has been demonstrated that the average appliance is operated so wastefully that the householder can utilize, to equally good advantage, gas of lower heating power, which can be supplied at less expense. Candle-power standards are still used by some few gas companies, but have disappeared from legal requirements.

Waste-heat boilers, despite their obvious advantages, have not yet come into general use in American gas works, though they have been introduced to some extent in water-gas plants. The use of continuous vertical retorts in the United States is, however, extensive and increasing.

Complete gasification is a goal to which the industry in this country eagerly looks forward. It has been the subject of extensive experimentation here, in some instances on the commercial scale, but so far as known to me, there is no plant in regular commercial operation. As I am speaking in advance of Mr. Ramsburg's paper of this afternoon, and without knowledge of its contents, I reserve the right to change my opinion after luncheon. Our own engineers have, however, recently inspected a remarkable and wholly automatic water-gas producer in Europe, which, operating without a boiler, provides steam in the balanced proportion required for the run, yields gas of 420 B.t.u. and, as desired, either completely gasifies the bituminous coal with which it is supplied or delivers coke continuously in any proportion within a wide range.

Mr. Orrok, in his paper of yesterday, shattered the hope which many, less well informed, have cherished, of super-power stations at the mine mouth. Gas works, however, are under no such limiting condition of water supply, and we are, I believe, destined to see super-gas works at the mines with high-pressure distribution over wide areas, to the great advantage of our industrial and domestic economies.

ALFRED T. CHILD.* Those of us in this country are pretty familiar with the outlets which coke finds here, but not so familiar with the outlet which coke finds in England. Do these furnaces produce only domestic grade coke or do they produce foundry coke, blast furnace coke, and so on? I would appreciate very much a statement of the outlets other than power for the plants.

GEOFFREY M. GILL. The coke produced by gas works in England is sold for a great variety of purposes. Industrial furnaces of all kinds take a portion; the open type of domestic grate used in England takes a portion; but the largest outlet is probably the small closed stoves used for domestic water heating.

The quantity of coke which can be sold in England is dependent upon good sales propaganda and the provision of the coke in suitably graded sizes ready for use.

A MEMBER. How much oil is being produced by the Fischer process now?

FRANZ FISCHER. I can say better after a few years.

C. J. RAMSBURG.† The work of Prof. Fischer is of great interest to the gas industry. I would like to ask him a very leading question, namely: do you feel that the work you have done would lead to the conclusion that it is going to be practically and economically possible by combining the components of blue gas to secure a high B.t.u. gas, such as methane, without the enrichment being necessary as at present with petroleum oils?

*Associate Professor of Chemical Engineering, Rose Polytechnic Institute, Terre Haute, Indiana.

†Vice-president, The Koppers Company, Pittsburgh, Pa.

FRANZ FISCHER. It is possible to make the methane directly, but then you are obliged to work along somewhat different lines than I gave in my paper.

A MEMBER. I was very much interested in the figures given by Mr. Gill on the yield by use of steam. I would like to know whether Mr. Gill has experienced using super-heated steam in connection with gas plants. There are gas plants in this country which are using superheated steam. Saturated steam contains moisture and this moisture has got to be first evaporated before it is converted into steam, which requires a considerable amount of heat. There was no change, I was told, in using super-heated steam and the retorts held much longer. As it was explained, saturated steam contained a percentage of moisture; in steam retort you have, to a certain extent, particularly in the lower part, explosions by evaporation of the moisture, and this causes carbon in the retort. I would like to know about this.

GEOFFREY M. GILL. At one time the steam used in continuous vertical retorts was not super-heated, but nowadays these plants are fitted with waste heat boilers in which super-heaters are provided, and consequently the steam now used is superheated.

A MEMBER. What is the practice in England and Germany with respect to the size of coal used in the horizontal retort? As I understand the slides, they are not nut size coals. As you know, every size is used in this country, everywhere from nut size to a 2-inch lump. No one has given any information on the size you are using or the number of sizes, of coal.

GEOFFREY M. GILL. No useful information can be given in relation to the sizes of coal used in England, except that all lump coal is broken to a size of 2-inches or less. Many works use run-of-mine coal; and this, in fact, is the usual condition of the Durham and Northumberland gas coals. At the same time a considerable quantity of screened coal is used, and where procurable "nuts" are much in demand for gas works' use.

I do not think that coal is screened into sizes in England to the extent that is done in the United States, and as a consequence, gas works have to use it as mined.

W. H. GARTLEY.* Tests have been made in the Philadelphia Gas Works to determine the relative values of the coke when carbonizing lump coal, run-of-mine and screenings, and it has been found that the result in a horizontal retort is very different from that obtained in a vertical retort. No general statement can be made that will apply to all methods of carbonizing.

I would like to inquire if we could get a little information on that method of purification that Dr. Little referred to. Also another thing, if in England where they have endeavored to make more coke for sale

*Chief Engineer, Philadelphia Gas Works, Philadelphia, Pa.

by substituting gas for heating, why have they not introduced gas producers, which would use the fines, thus making available the gas and coke for sale? Such producers do not appear to have been largely utilized.

Geoffrey M. Gill. In reply to the question as regards the reason that mechanical producers using fine coke have not been adopted in England, it must be remembered that the quantity of coal gas made greatly exceeds the quantity of water gas, and as a consequence there is always a considerable quantity of coke to dispose of, often more than can be readily sold.

As a result more thought has been given to finding markets for the surplus coke than to methods of increasing the quantity produced.

I think this is the reason that mechanical producers to use small coke and breeze have not often been seriously considered for the heating of retort settings.

Frank M. Gentry.* The work of Prof. Fischer in the field of liquifaction of coal is of great industrial importance. Fischer seems to have devoted his attention to two lines of experimentation, hydrogenation through the agency of formic acid or its derivatives and synthesis of liquid fuel from the oxides of carbon in the presence of catalysts and under controlled physical conditions.

Whatever the mechanism by which sodium formate, carbon monoxide and water, or hydrogen and sodium bicarbonate effect liquifaction of coal, there is evidence of the formation of nascent hydrogen. It would be natural to presume that hydrogenation would take place under less severe physical conditions when nascent hydrogen is substituted for the molecular gas.

It has long been known that even at pressures exceeding 200 atmospheres that carbon monoxide and hydrogen could not be made to react at any temperature except through the agency of a catalyst. The production of liquid fuels from gases has, therefore, reduced itself largely to the search for suitable catalytic agents to effect the desired transformation. The catalytic action of finely divided pure metals, while bringing about the formation of methane, do not seem to be able to convert carbon monoxide and hydrogen to liquid products under any conditions of pressure and temperature. Fischer, however, made the important discovery that when combined with other agents such as strong bases to form binary catalysts, finely divided metals produced the desired liquid products together with certain fixed gases.

Different catalysts give different reaction products. Thus while Fischer obtained "synthol," a mixture of 10% fatty acids, 29% alcohols, aldehydes and ketones and 61% oils, using iron and caustic potash as a binary catalyst, Audibert at the Societe Nationale de Recherches

*Assistant to the Consulting Engineer, The New York Edison Co. (Submitted in writing after the close of the meeting.)

sur le Traitement de Combustibles obtained almost pure methyl alcohol with a 100% yield on the reacting gases using suboxides as catalysts.

Audibert has pointed out that Fischer obtained only 22% to 27% conversion of heat units from gas to liquid by recirculation over the catalyst in a closed circuit with condensation of the products. He does not forecast success in obtaining much better results for two reasons, first, because the reactions effected by the iron-alkali mixture are all exothermic, releasing in sensible heat about 20% of the potential heat in the gas, regardless of whether gaseous or liquid products are obtained and, second, the loss of energy in liquid form, resulting from conversion of a large part of the reacting gases into methane and carbon dioxide. This is a serious disadvantage for the economical liquifaction of coal for motor fuel unless means can be devised to condense the methane. By producing pure methyl alcohol with the use of suboxides, Audibert has obtained a thermal conversion of 82% for the calorific value of the liquid referred to that of the initial gases.

SOME NEW USES FOR PULVERIZED COAL

By WALTER E. TRENT
Vice-President, Trent Process Corporation, New York

INTRODUCTION

In addition to the wonderful and marvelous chemical processes now available for the higher utilization of coal, the industrial world needs new and simple uses for coal, as coal. It needs better ways to burn coal than present methods, and a knowledge of how to make coals fulfil the present uses of oil.

This paper proposes, largely, means of handling coal to replace oils. It presupposes a knowledge on the part of the delegates that ash can be removed from coal when it is pulverized to 200-mesh and finer. It will later be described how coal, as coal, without chemical conversion, is made to flow, and run, and answer all the common laws of liquids.

In November, 1918, the speaker, then an officer in the U. S. Army Engineers, presented to the War Department a new design of internal combustion engine suited to the use of coal dust instead of oils. After due investigation the project was accepted for development by the Invention Section of the War College, and the development was carried out at the Bureau of Standards. The reports of the Bureau will be read so that the subject matter of the paper will be better understood.

HCD:FRP October 23, 1926.

Mr. Walter E. Trent,
Trent Process Corporation,
52 Broadway,
New York, N. Y.

Subject: Enclosing report

Dear Sir.

1. Your letter of October 19, addressed to Dr. H. C. Dickinson. has been referred to this Bureau for official reply.

2. We are enclosing herewith copy of report forwarded to you under date of August 16, 1921. This report is entitled "Report on Results of Research Undertaken by Mr. Walter E. Trent at the Bureau of Standards," and was made at the request of the Inventions Sections, General Staff, United States Army.

Enclosure:
Report

Respectfully,
GEORGE K. BURGESS, Director.

REPORT ON RESULTS OF RESEARCH UNDERTAKEN BY MR. WALTER E. TRENT AT THE BUREAU OF STANDARDS

Washington, D. C.
March 13, 1919.

Requested by:
Inventions Section,
General Staff U. S. A.

At the request of the Inventions Section, General Staff, U. S. A., the Bureau of Standards examined and reported upon a proposal of Mr. Trent for the development of a form of engine combining some of the characteristics and advantages of both the steam and the internal combustion type. Following this report and at the request of the Inventions Sections, factilities were afforded Mr. Trent for the development in this connection of a device for producing the required combustion of fuels under pressure. Subsequently this led to the discovery of means for burning pulverized coal as well as liquid fuels, in a generator under pressure.

The original proposal of Mr. Trent involved the design and perfecting of (1) means whereby fuels of the widest possible range could be burned under pressure in a closed contained or generator; (2) means whereby the products of combustion could be reduced in temperature by the addition of water or steam to such a point that they could be used in a reciprocating steam engine or prime mover of similar type; (3) the development of an engine which would combine a compression unit and a power unit to supply air and expand the products of combustion for the generation of power, and (4) means for utilizing the jacket and exhaust heat to heat the water or to produce the steam for mixing with the products of combustion.

Mr. Trent first undertook the design of a generator for effecting combustion under pressure and cooling the products of combustion. After considerable experimentation this seems to have been successfully accomplished and fuels both solid and liquid, ranging from kerosene to powdered coal, have been successfully burned under a pressure of about 50 lb. per sq. in. Facilities for carrying on the combustion under higher pressures have as yet not been available, but no serious difficulties in the use of pressures to 150 lb. per sq. in. are foreseen.

In studying the technique of burning pulverized coal in the generator, it was found that the ash content of such coals as were available was such as to render their use for more than a short time impossible on account of the accumulation of ash. To avoid this difficulty Mr. Trent undertook to develop means for reducing the ash content from pulverized coal, and has developed a process which offers promise of industrial applications other than for the purpose for which the process was originally proposed, as for instance

in any process where pulverized coal with a low ash content can be used to advantage as compared with coal containing the usual amount of ash.

Briefly the proposed process of ash removal consists in (1) pulverizing the coal, which may be done wet, to a 200-mesh size more or less depending upon the nature of the coal and the degree of ash removal desired; (2) mixing the pulverized coal with water, the amount of water being of the order of 200% of the coal weight; (3) adding to this mixture a mineral oil to the extent of roughly 50% of the coal weight; (4) agitating the mixture until the coal and oil agglomerate, rejecting most of the water; (5) scrubbing the agglomerate coal and oil with water, removing the silicious matter, or ash forming materials.

Previous to the addition of the oil the coal may be washed to remove iron sulphide as has been practiced heretofore.

The application of this process exclusive of the washing to remove iron sulphide has been witnessed a number of times by members of the Bureau staff, when applied by hand to small samples (1000 gr.) of coals of two different compositions with the results given in the accompanying tables.

From the results of tests made at the Bureau of Standards, it is concluded (1) that a wide variety of fuels including pulverized coal can be burned successfully in a generator under pressure provided the fuel does not contain too great an amount of ash.

(2) That the removal of a considerable percentage of mineral matter from coal (at least from certain coals) can be accomplished by the oil flotation process herein described.

(3) The industrial importance of this process will necessarily depend upon the cost of applying the proposed treatment, and the increase in value of the coals treated for any particular use; neither of which can be estimated from the information at hand.

The following tests were made to determine the characteristics of the agglomerate of coal and oil as produced by the Trent process:

TABLE I.

Physical Examination of Agglomerates after Cleaning.

	Lehigh Coal		New Jersey Zinc Coal	
	grams	per cent	grams	per cent
Wt. of agglomerate.....	30.523	100	39.668	100
Wt. of distillate (Water and Oil)	13.251	43.5	21.485	54.2
Wt. of residue (coal and ash)	14.572	48.2	16.495	41.6
Loss		8.3		4.2

TABLE II.

Examination of Distillate from Agglomerate.

	Lehigh Coal		New Jersey Zinc Coal	
	C.C.	per cent	C.C.	per cent
Volume of distillate	17	100	23	100
Volume of water	5	30	11	48
Volume of oil	12	70	12	52

TABLE III.

Distillation temperature of gas oil used in agglomeration of coal.

Volume Distilled	Temperature of Distillation
*I. B. P.	209° C.
10%	250° C.
20%	267° C.
30%	276° C.
40%	284° C.
50%	294° C.
60%	298° C.
70%	316° C.
80%	325° C.
90%	350° C.
95%	363° C.
97%	375° C.

Proximate analyses were made of the two samples of coal before and after treatment to determine the extent to which the ash was removed by the process.

TABLE IV.

Coal 3rd Vein Screening—New Jersey Zinc Coal.

Lab. No.	Original 58492		After Treatment 58493	
	As Rec'd.	Dry Basis	As Rec'd.	Dry Basis
Moisture	10.1	.....	0.4	.....
Volatile	36.9	41.0	39.7	39.9
Fixed Carbon	41.4	46.1	52.8	53.0
Ash	11.6	12.9	7.1	7.1
B. t. u. per pound	11,100	12,400	13,150	13,200

*I. B. P.—Initial boiling point.

COAL FULLER LEHIGH

Lab. No.	Original 58494		After Treatment 58495	
	As Rec'd.	Dry Basis	As Rec'd.	Dry Basis
Moisture	1.5	.....	0.2	.....
Volatile	32.5	33.0	32.0	32.1
Fixed Carbon	52.2	53.0	57.3	57.4
Ash	13.8	14.0	10.5	10.5
B. t. u. per pound	12,850	13,050	13,550	13,600

NOTE: The values given for heat of combustion of the treated samples are computed from those for the untreated fuels, on the assumption that the heat of combustion of the combustible material in the coal is unaffected by the process of ash removal.

It was found that by removal of a certain portion of the oil by distillation after cleaning and washing, the coal could be reduced to the same loose condition as that of the original sample. Samples of the two grades of coal were heated gradually until they reached this condition, and tests were run for volatile matter with the following results, which show a rather large amount of volatile matter remaining after treatment. It is believed that this fact may be of importance in case dry pulverized coal of high volatile matter is desired.

TABLE V.

LEHIGH COAL POWDER WITH OIL

Weight of mixture	14.780 gr.	100%
Weight after drying to powdered condition	11.216 gr.	
Weight after heating red (coke)	5.817 gr.	
Water and oil evaporated	3.864 gr.	24%
Loss on coking	5.405 gr.	37%
Per cent of dry powder that is volatile		48%

COAL OF NEW JERSEY ZINC CO.

Weight of wet mixture	17.692 gr.	100%
Weight after drying	10.900 gr.	
Weight after coking	6.347 gr.	
Water and oil evaporated	6.792 gr.	38%
Loss on coking	4.553 gr.	26%
Per cent of dry powder volatile		42%

Washington, D. C.
November 28, 1919.

(Signed) S. W. STRATTON,
Director.

A TRUE COPY,
January 31, 1921.
EMS

Some New Uses for Pulverized Coal

In 1876, just fifty years ago, a reverberatory furnace was fired with pulverized coal at the Swansea Smelter at Denver, Colorado. The smelter was in charge of Mr. Leopold Balbach, of the well-known smelting family of New Jersey.

The actual burning of the pulverized coal was successful because of the long flame and high temperature attained in the furnaces. The coal pulverizing was performed by "Burr Millstones," which were the only drawback to the method, as the stones required too much "dressing" to keep them smooth, and it was only the lack of better pulverizing methods that caused the abandonment of the operation and retarded a general adoption of pulverized coal for smelting.

The cement and metallurgical industries, during the last fifteen years, have established the value of pulverized, high volatile coals for their respective industries. Both require long flame combustion and both contend successfully with the coal ash by absorbing that part which settles into the clinker or slags.

Steam generation with pulverized coals is now a successful and growing business and the most extraordinary skill has been displayed in its accomplishment; but much remains to be done to bring pulverized coal boiler firing to the state of simplicity and reliability of either coal stoker firing or the burning of oil. While giving full acknowledgment to the success attained in central station power plants, it is a simple truth to say that today the preparation and burning of pulverized coal is in an incipient stage. It has merely reached a point comparable to that of a baby when it first learns to walk.

The success attained at this time represents ingenuity in contending with the difficult conditions that beset the art rather than in eradicating them. The difficulties are recognizable, therefore their solutions are a matter of course.

A discussion of new uses for pulverized coals requires consideration of all classes of coals, ranging from anthracites to lignites, but they can all be considered under three general characteristics: namely, heating value, chemical value (in terms of by-products), and physical properties (relating to the hardness and

density of both the coal and accompanying impurities). The expanded uses of pulverized coals depend upon recognizing and treating with these three fundamental phases.

Electric Vibratory Pulverizer

Pulverizing is an art that can be performed most efficiently in stages. The hammermill makes an ideal size (¼" and finer) to feed the standard tumbling barrel types, containing rods, or bells, which are now used for 200 mesh pulverizing, but all such mills are better suited to make a product of minus 20 mesh than they are to make a product of minus 200 or finer.

Of the tumbling barrel type, the balanced rod mill has been found to have great efficiency on account of power saving of one-third over the ordinary types, but it has become necessary to develop a fine pulverizing mill that will start at 20 mesh, or thereabouts (the size most efficiently produced by present mills), and make 200, 300, 500 and even 1000 mesh material.

The Electric Vibratory Pulverizer has been devised for this purpose. The principle of loosely assembled pulverizing elements is preserved, but they are very much smaller in size and they are vibrated vertically instead of being cascaded in a barrel. This vertical vibration is very rapid, 60 times per second. The amplitude of vibration is ordinarily ⅛", but it may be more or less. The Vibratory Pulverizer is illustrated in connection with the balanced rod mill, showing the two units working in series, to carry the coal from hammermill size to minus 300 mesh.

The Vibratory Pulverizer consists of a vertical, cylindrical shell, which is filled with short and small diameter rollers or balls. This container is fastened to a floor resting on rubber pads, and to the underside of this floor is fastened a Mitchell Electric Vibrator, the same as is used on the well-known Mitchell Screen.

The material to be pulverized is passed between the elements, which are caused to roll and turn in relation to one another by the extremely rapid state of vibration of the container. The pulverizing is due more to this rolling and rubbing action, set up by the constant turning and movement of the elements, than it is to any hitting action, or clicking of the elements. The action is really one

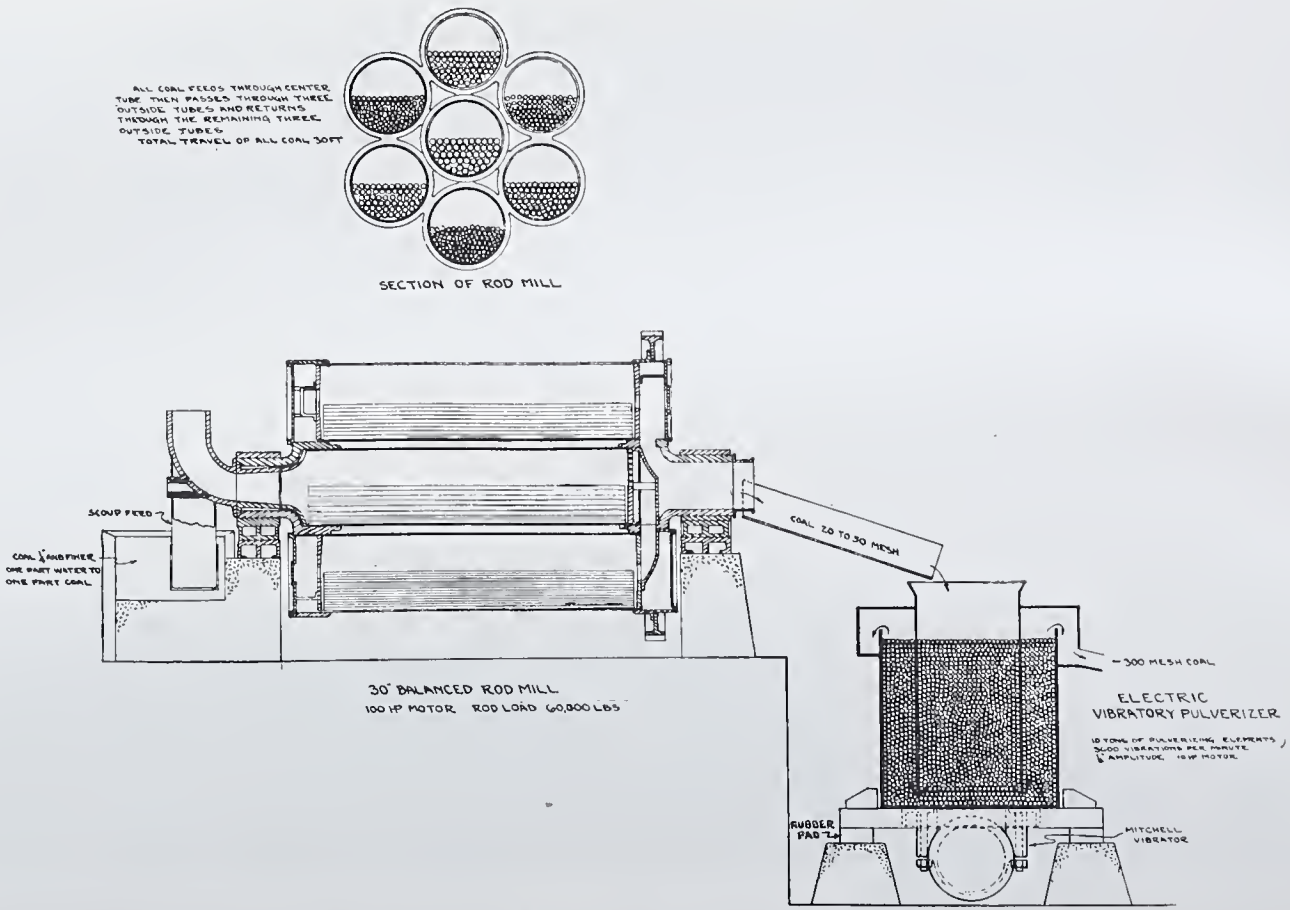

ALL COAL FEEDS THROUGH CENTER TUBE THEN PASSES THROUGH THREE OUTSIDE TUBES AND RETURNS THROUGH THE REMAINING THREE OUTSIDE TUBES
TOTAL TRAVEL OF ALL COAL 30FT
SECTION OF ROD MILL
SCOOP FEED
COAL & WATER ONE PART WATER TO ONE PART COAL
30' BALANCED ROD MILL
100 HP MOTOR ROD LOAD 60,000 LBS
COAL 20 TO 30 MESH
-300 MESH COAL
ELECTRIC VIBRATORY PULVERIZER
10 TONS OF PULVERIZING ELEMENTS
3600 VIBRATIONS PER MINUTE
& AMPLITUDE 10 HP MOTOR
RUBBER PAD
MITCHELL VIBRATOR

FIG. 1. TRENT TWO STAGE PULVERIZING SYSSTEM FOR BOTH WET AND DRY PULVERIZING

of rolling attrition, especially when making products of ultra fine grinding.

This principle provides a pulverizer in which all of the elements are working at every given moment, which is new. The working rate is the fastest ever applied. It is too early in the development of this machine to give efficiencies and capacities, but 10 horse power will vibrate 10 tons 3600 times per minute, with ⅛" amplitudes. Both efficiency and capacity promise to be revolutionary.

A photograph is given of the first Electric Vibratory Pulverizer. This little machine contains 800 pounds of small, steel balls. The Mitchell Vibrator motor, rated at 1 horse power, shows power consumption of .7 of 1 horse power.

Fig. 2. The First Electric Vibratory Pulverizer Using Mitchell Standard Vibrator
Outer Shell 18"x18"
Ball Load 800 lbs.
Vibrations 3600 per minute
Amplitude of Vibrations 1/16"
Made by C. W. Hunt & Company
West Brighton, Staten Island

Anthracites

As anthracite coals are a simple but very important class they will be considered first, and as they have no interesting economic chemical characteristics, it is necessary only to discuss their heating value and physical properties. Their unit heating power is relatively low, even when considered on an ash free basis, because of their low hydrogen content. The ash content of all coals will be discussed later as a separate subject.

The physical properties of anthracites are profoundly important. American anthracites are hard, dense, and have a high percentage of carbon, consequently they burn only at high temperatures, but even so at a uniform and sustained rate, which, at present, make them the premier solid domestic fuels. On account of hardness the pulverizing is both slow and difficult, and because of density and lack of hydrogen anthracites have to be pulverized to far finer sizes than bituminous coals; but if powdered to an ultra fine degree they burn freely and insensitively when carrying both constant and variable loads. Anthracites, when reduced to 300 mesh, with comparable percentages of smaller sizes, burn as freely as bituminous coal at 200 mesh.

If anthracite is to be burned in a suspended state, it will require exceedingly fine pulverizing at a permissible cost. The same is true if steam and waste coal is to be reconstructed into sizes suitable for domestic use.

On account of the extraordinary qualities of anthracite as a domestic fuel, it seems that the accumulated millions of tons of culm and silt should be reconstructed into domestic sizes, but unsaleable accumulations usually take the quickest and cheapest course offered, which, with cheap pulverizing of anthracite, will be the steam market. Later, no doubt, all current production of steam and smaller sizes will undergo pulverizing, de-ashing and reconstruction into the domestic sizes as a means to lower costs to meet the competition of anthracite equivalents arising from the modern methods of treating bituminous coals.

Semi-Bituminous Coals

There is little to be said about semi-bituminous or low volatile coals, because if and when they are sufficiently finely pulverized, which must be to a state finer than that attained by present practice, they are

obviously ideal from every standpoint. They are very soft; they have the highest heat value; they do not justify chemical treatment in advance of burning, because they yield only negligible quantities of by-products, and in such pulverized form they are comparatively safe to store and handle.

Bituminous Coals

Bituminous coals are used almost exclusively at present by the industries that pulverize for direct burning. A great advance in the uses of pulverized bituminous will depend upon the following steps: cheaper and finer grinding, the intermediate treatment for oils and gas, and the adaptation of the carbon residue to many uses beside boiler and furnace firing. Finer grinding will permit the use of shorter fire boxes and furnaces. With coal 300 mesh or finer, they will be neither higher nor longer than those needed to burn oil. The high volatile coals now considered necessary will be augmented by lower volatile ones thus made adaptable to the same conditions.

With ultra fine grinding the successful firing of locomotives with pulverized coal will become a reality, because combustion can then be completed within fire boxes of the present dimensions. The same is true in firing the boilers of steamships, especially if a pulverizer of simplicity and efficiency is adapted to the ship equipment.

Innumerable plants and factories will adopt pulverized coal for separated unit firing if all general classes of coals are made suitable, if short flame lengths can be attained, and if the pulverized coal can be used with the ordinary safety of coarse coals. Any and all coals are burnable with short flame lengths, if sufficiently finely pulverized.

Lignites

If ash content be ignored, the ultimate analyses of lignites are almost identical with those of carburetted water gas. The water is there, representing the hydrogen and oxygen; the carbon is there; and the volatile hydrocarbon, corresponding to oil gas, is there also. When pulverized lignites are carried through a zone of proper heat with a small addition of water or steam, the result is an enriched water gas.

Lignites are friable and easy to pulverize. They do not soften, melt, or get sticky during gasification or carbonization, consequently, there is no difficulty about carbonizing them in powder form, and these

treated powders are easily amalgamated and baked into Superfuel.

Lignites and iron ores occur in the same localities in many places and are complementary raw materials for the manufacture of iron and steel by the direct processes.

All that may be said of lignites may be said of sub-bituminous coals. It is time that their uses be expanded. Industries and population concentrate about fuel deposits which are efficiently utilized. The opportunity is now presented to convert lignites and sub-bituminous coals into oil, gas and anthracite equivalent, to use them for the production of iron and steel, and to develop a position in locomotive firing.

Coal in a Mobile State Answering the Laws of Liquids

The most useful and valuable of all the characteristics of coal is the last to be taken advantage of, and offers to solve in all respects an efficient continuous method for carbonizing coal. Pulverized coal can be made to flow, and run, and seek its own level. The mere heating of pulverized bituminous coal to a point at which vapors are generated (either chemical water or hydrocarbon) gives to the coal a state of great mobility. In this condition it resembles liquids and answers the common laws of liquids. The coal particles become enlivened by the vapors issuing therefrom. These vapors form bubbles, or casings, around each and every particle, and reduce friction to such a degree that the angle of repose of the coal becomes horizontal, level.

As long as vapors, or gases, are issuing from the particles, the coal retains this liquid-like condition. Its range is from the low temperatures at which distillation first commences, right through to the highest distilling temperatures, but the heating must be gradual.

When it becomes possible to treat coal as a liquid instead of a solid, the coal industry and all coal technique must undergo a change. The mining of coal, its transportation, its burning, its carbonization, and its gasification, will be affected. It looks as if a big industry has to be done all over again.

Transporting Pulverized Coal

All present transporting systems use air commingled with the fine coal in some quantity or other. The signal is set for danger whenever extraneous air is commingled with coal dust, whether it be by applying air pressure in a tank to push the coal through pipes or by carrying the

coal in air suspension, or even by adding comparatively small charges of air to assist in ramming or pumping the coal. Therefore, to be assured of safety, coal must be transported without the presence of air, even that which ordinarily occupies the spaces between the particles.

It has already been described how coal can be made to flow and to pump. The best, the simplest and the safest way to transport coal from the point of pulverization to the points of consumption is by flowing or pumping same when it has been heated to the vaporizing point, and thereby placed in a mobile condition. These vapors displace the air which would normally occur between the coal particles, and, therefore, the coal will be transported without the presence of any air whatsoever.

The Necessities and Uses for Carbonized Coal Powder

The subject of carbonization, so far as this paper is concerned, is confined to treating pulverized coals to produce therefrom carbonized powder as the primary product, with gas and low temperature oils as secondary ones. Carbonized powder and products reconstructed therefrom, can be used for every purpose for which all classes of solid fuels are now used, and usually at less unit cost and with greater efficiency.

Carbonized coal dust is a perfect fuel for central station power plants and all steam raising plants and furnaces. Carbonized powder is convertible into lumps of all desired shapes and sizes, which burn smokelessly, leaving no clinker and having all of the characteristics of the very best anthracite coals. These reconstructed fuels will make American cities smokeless. Carbonized coal dust, freed from its clinkering constituents, is ideal for the manufacture of blue gas and producer gas.

Direct Iron and Steel Process

Pulverized coal and its carbonized powder, commingled with pulverized iron ores, are the raw materials of the direct processes for producing iron and steel. The coals may be non-coking, even lignites. Any variety that happens to be adjacent to the iron ores, or adjacent to consuming centers to which iron ores are cheaply transportable, is suitable for this purpose. In the direct processes the fuels are burned to

completed products of combustion, therefore requiring the use of little more than half as much fuel as do present standard practices to produce the same amount of metal.

Gas Made by Low Temperature Distillation

The gases derived from the low temperature distillation of coal have many uses, the most important one being as city gas. Both the yield and heating value vary according to the coals used, but they also vary with a given coal according to both time of treatment and the temperature. When pulverized coals are uniformly heated, the volume of gas increases with the time of treatment, and also with an increase of temperature. Low temperature distillation may be conducted at 450°C. as the low limit, and at 700° C. as the upper limit. A given coal will yield say 5000 cubic feet of gas at 450°C., and as much as 8000 cubic feet at 700°C. The heating value will vary between 750 to 950 B.t.u. per cubic foot. When a low temperature operation is conducted for maximum gas yields it is quite possible to produce 75 to 80% as many heat units in the form of gas as it is in gas retorts, or high temperature ovens. Being a very much richer gas than the usual mixtures of coal and water gas, it has advantages in both distribution and burning characteristics. It is sufficiently rich to mix with ordinary blue gas to meet present gas standards.

The limitations of coke markets restrict the amount of gas that can be sold when made in by-product coke ovens. Low temperature gas, when made as a by-product of carbonized powder, can be made and sold to the point of saturation, because the markets for carbon dust and products made therefrom are so large and diversified that they have no practical limitations in relation to the total gas requirements of a given area. Thus the situation becomes reversed—the amount of carbon powder that can be made and disposed of in a district may be limited by the ability of the area to consume gas. This is as it should be, because the consumption of solid fuels is many times the coal equivalent of the gas consumption.

The relatively low heating value of coke oven gas, together with the high price of gas oil (and the expectation of higher prices), fully justifies the lowering of heating standards of gas, in order to lower the cost of unit heat production; but in view of the great and varied uses for carbonized powder, and the very rich gas accompanying

its manufacture, it is certain that raising the heating standards will become desirable in the future. The low temperature gases are almost twice as rich as the low standards that many advocate, they are made exclusively from coals, and a great and cheap variety of them.

If a high standard gas can be produced at lower cost per B.t.u. than a low standard gas, then every reason dictates its use both from the standpoint of the manufacturers and the consumers.

A Distillation Method to Produce Carbonized Powder

It is true that coarse coal may be distilled at low temperatures to produce semi-coke, which may be pulverized and put to all the uses herein mentioned; but the distillation of pulverized coal offers an opportunity to take advantage of the flowing, mobile condition of heated pulverized coal. It offers the incomparable advantage of carbonizing in stationary shell and tubular stills, and effecting heat exchange between the hot finished carbonized coal dust and the incoming pulverized coal. It offers a further great reward, that of reclaiming part of both the sensible heat and the heat of vaporization of the products of distillation, by transmitting same to the incoming coal. Heat exchange, which is heat conservation, or heat efficiency, is just as valuable, desirable and necessary in the carbonization of coal as it is in power generation. There must be no waste of heat in carbonizing coal. In coke ovens about 35% of the total heat generated is contained in the white hot coke when it is pushed from the ovens, and nearly 30% of the total heat is carried away by the products of distillation. At least part of such heat losses can be returned to the incoming coal, if this incoming coal and the finished carbonized powder answer the common laws of liquids, so that heat exchange is possible between a hot flowing material separated only by a metallic wall from a comparatively cold flowing material.

The actual decomposition of coal generates heat and only those methods that conduct carbonization on a basis of thermal efficiency—the basis that measures the value of power generation—will have a major place in general industry when the low temperature carbonization of coal becomes a commercialized procedure.

It will occur to those who are familiar with existing carbonizing practices that the flowing method will work well with non-coking coals

but not with coking ones. It is to be understood that coking coals, when pulverized and heated, have the same properties of mobility and flowing as have the non-coking ones. There are two successful methods of utilizing coking coals in a flowing retort; one is to resort to well-known methods of preheating and agitating pulverized coking coals in the presence of air, so as to destroy completely all fusing and agglomerating characteristics, and then of sending this heated material through the retort. The second method is based on observations and experiences which show a complete destruction of the natural fusing and agglomerating characteristics of powdered coking coal by a new method, the nature of which is as follows: if a slowly moving stream of coking coal powder is very slowly heated, so that complete devolatilization takes place at every stage of the gradually increasing temperature, and if the expelled vapors of the slowly moving column of particles are compelled to travel with and pass around the slowly moving particles, then no agglomerating will take place. The particles must be so small that the enveloping vapors will absorb and carry off some of the heat that is generated when the decomposition of the coal sets in, because if not removed, it will cause an altogether too rapid increase in the temperature of the coal, resulting in fusion.

In order completely to prevent agglomerating, strong coking coal particles should be under heat about five hours before exceeding the temperature at which they normally soften and enter the plastic condition. It is necessary to keep the vapors commingled with and traveling faster than the coal particles to the zone of complete carbonization. In this process the finely pulverized coal moves as a column very slowly through the heating zone of the retort. It flows as a liquid, but the velocity is deliberately retarded so as to attain a slow rate of carbonization, and also to prevent a too rapid ebullition of gas, which would cause the powder to get into actual gaseous suspension, thereby creating a dust problem.

The accompanying diagrammatic sketch shows a vertical cross section of a flowing type of retort, through which the coal is flowed or pumped. It will be observed that there is a fire or hot gas box at the bottom, with a multitude of 1½" fire flues which extend vertically and connect with a smoke box at the very top of the retort. The surfaces of the 1½" vertical pipes are the surfaces that heat the coal. A short distance below the floor of the smoke box, which is the upper header

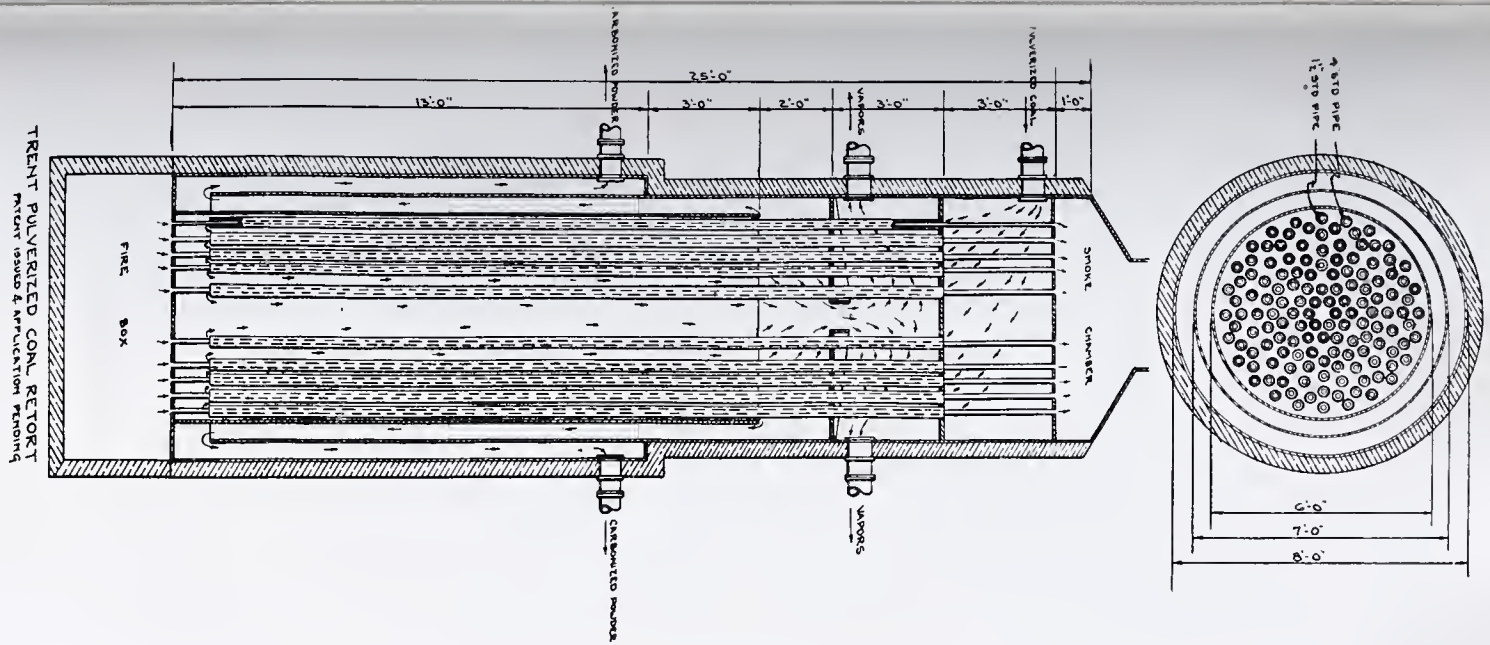


FIG. 3. TRENT PULVERIZED COAL RETORT

RETORT DATA

1-Shell 6′ I.D. and 16′ Long.
138-1½″ Tubes 24′ Long.
138-4″ Coal Pipes 20′ Long.
Total Cross Section Area of 1½″ Tubes = 1.65 Sq. Ft.
Total Cross Section Area of Coal Pipes = 11.04 Sq. Ft.
Total Cross Section Area of 4″ Pipes Containing Coal = 9.39 Sq. Ft.
Total Cross Section Area of Inner Shell = 28.27 Sq. Ft.
Total Cross Section Area Containing Coal Outside 4″ Pipes = 17.23 Sq. Ft.
Total Heating Surface of 1½″ Pipes = 1300 Sq. Ft.
Total Surface of Coal Pipes = 2890 Sq. Ft.
Depth of Coal in Inner Shell = 16 Ft.
Volume of Coal in Inner Shell = 425.92 Cu. Ft.

for the fire flues, is placed another floor header. Surrounding all of the 1½″ fire flues, and expanded into this header and suspended therefrom, are the 4″ pipes which stop short of the bottom of the retort and are open. (See Fig. 3.)

Between the two headers mentioned is a space which becomes the coal feeding space. The coal feeds through the 4″ pipes in contact with the 1½″ heating flues, and slowly descends at the rate of only a few feet per hour in this annular space between the outside walls of the heated 1½″ pipes and the annular walls of the 4″ pipes. The 4″ pipes, which carry the coal downward, terminate about 6″ above the floor or header that separates the body of the retort from the fire box. The coal flows out of the 4″ pipes into the main body of the retort and rises into the open spaces between the 4″ pipes to the annular overflow weir 16′ above the floor of the retort proper and 5′ below the point at which the coal feed enters the 4″ pipes. The coal then flows over the top of the annular weir and downward in the space between this weir and the annular wall of the shell of the retort, and at the bottom of this space the coal reverses and again flows upward into an annular space between the retort shell and an outer shell to the point of discharge, thus establishing a seal to prevent the escape of gases at this point.

The vapors and gases which are generated by heating the downward moving column of coal are compelled to travel with the coal, and they discharge out of the 4″ pipes and rise with the coal.

At the weir level, where the fine carbonized coal overflows, the products of distillation separate and ascend above the surface of the coal level and circulate in contact with the upper part of the 4″ pipes containing the incoming green coal. By circulating these vapors around the coal pipes a considerable amount of the heat of the vapors may be imparted to this incoming coal. A floor with a vapor opening collects any condensates and prevents drippage into the coal charge. The products of distillation are removed through an eduction pipe for further condensation and separation.

It is a definite object of this process to produce primary products of distillation and therefore the temperature is kept at the very lowest point, but maintained for a sufficient length of time to give maximum yields without decomposition of the products. It is also an important

object of this process to produce carbonized powder that has had a uniform treatment and therefore has a uniform composition and texture.

When the coal is first introduced to the feeding chamber of the retort, it gets a preliminary heating from the upper ends of the 1½" heating flues, which pass through this feed box before entering the smoke box. Then the coal follows downward in contact with the surfaces of the 1½" pipes, and the temperature gradually increases during the entire travel downward. Owing to the exothermic reaction of the coal the temperature continues to increase during part of the upward travel, and the maximum temperature of approximately 500° C. is reached about half way between the floor of the retort and the overflow weir, the distance being about 8'. During the balance of the upward travel through the overflow weir of about 8', the hot carbonized particles are transmitting heat to the outer shells of the 4" pipes, which contain the incoming coal. Therefore a very large part of the sensible heat of the finished carbonized powder is reclaimed and returned to the incoming coal. The carbonized coal itself, after entering and filling the annular space between the weir and the shell of the retort, prevents all radiation of useful heat from the body of the retort itself.

It will be seen that the system offers the highest possible thermal efficiency by reason of the fact that retort radiation is almost entirely prevented, and that certain important percentages of the sensible heat of the carbonized particles, as well as the distillation, are returned to the incoming coal.

The steel tubes will be chromium plated inside and out. This plating gives the tubes permanence, because chromium will not react with carbon. It prevents corrosion of the steel and affords a very smooth frictionless surface.

Carbonized Powder in Vaporous Suspension

The evolved vapors and gases of finely pulverized bituminous coal can be made to entrain and carry away the carbonized particles from which they are distilled, if the coal is first pulverized to 500 mesh. During distillation the coal must be moved as a column, as in the flowing retort, and moved and heated rapidly. Either all, or a greater part of the coal then ascends in a gaslike form,

the vapors entraining and carrying the minute carbonized particles. If this vaporous mass is not permitted to cool and undergo partial condensation, it answers the laws of gases. With coals having 35% volatile or more, sub-bituminous coals and lignites, this result is obtainable at temperatures of 500° C. or less. This gas-like condition affords another way to transport coal safely and efficiently. For industrial plants, having many and separated points of firing, it constitutes a gas equivalent. It contains more heat units per cubic foot than does the richest natural gas. It is adaptable to internal combustion for the generation of power. It is, for all practical purposes, vaporized coal.

Coal Purification and Ash Control

Ash is a valueless but costly constituent of all coals and its disposal is always necessary. It may be done before the coal is burned, during the burning, or afterwards—the latter being the prevalent practice with lump coals.

Domestic fuels should be purified to the highest possible degree for reasons obvious to all householders, and the best opportunity to clean coals is when they are in a pulverized condition. Coals used for making coke and gas should be purified at least to the point of having a non-clinkering ash residue. Coals that are to be burned in suspension should be purified. The ash should be removed so far as possible before combustion, and also (by modified methods of burning, one of which is illustrated in Fig. 4) during combustion.

The ash of pulverized coal should not be discharged into the atmosphere. Trouble is already arising from this practice and it is now clear that ash isolation is one of the fundamental requirements of future pulverized coal burning. There is not now any well-known process for de-ashing dry pulverized coals. One in process of development is a combination of the flowing idea coupled with the vibrating motion as now applied to pulverization. Other dry cleaning methods give promise. It is a field worthy of investigation and a development that is absolutely necessary.

The Wet Method—Amalgamation

This process is based upon three natural phenomena: the first, that when coal is very finely pulverized, the ash and clinker-

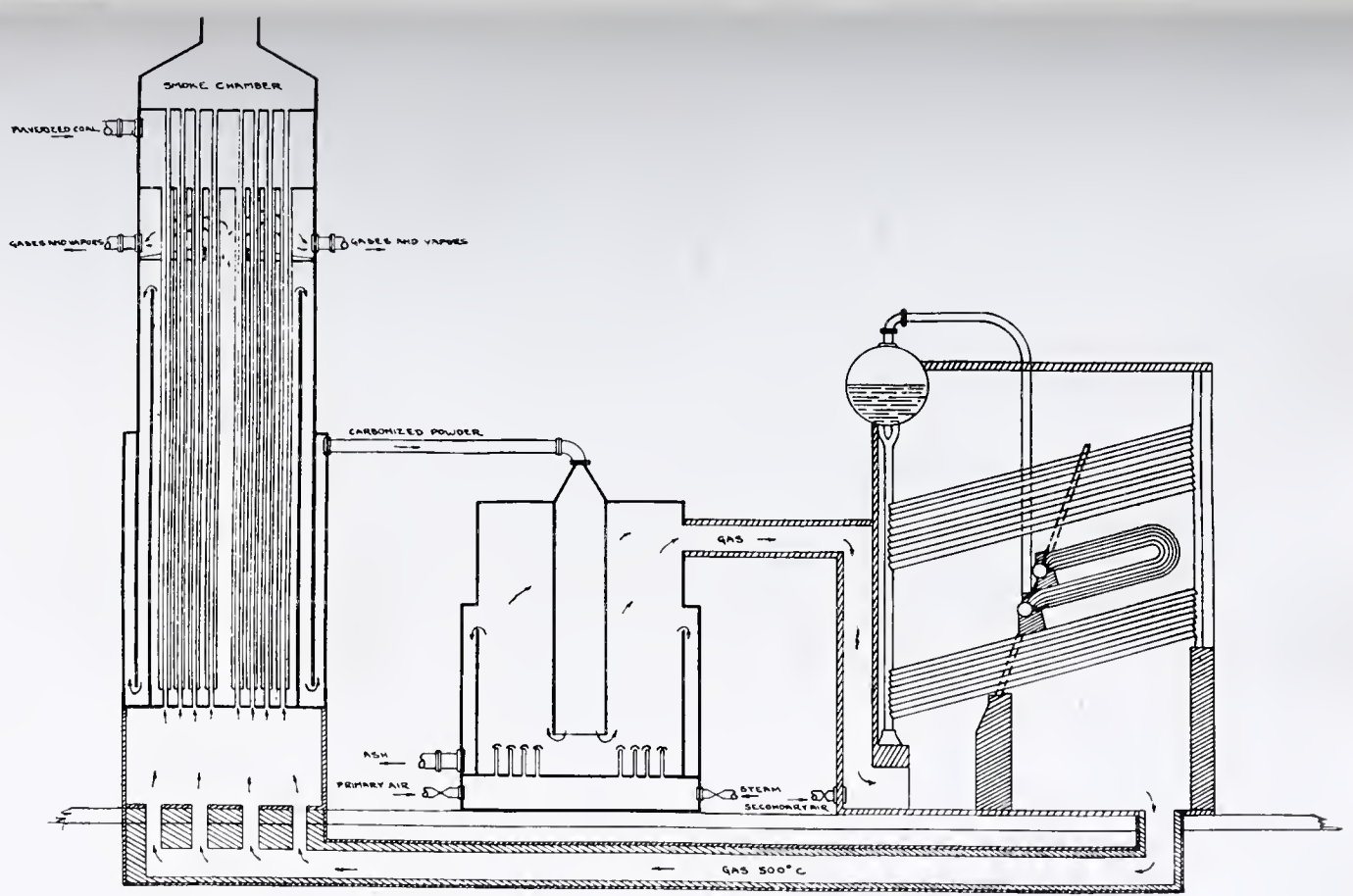


FIG. 4. GENERAL ARRANGEMENT OF BOILER PLANT EQUIPPED FOR LOW TEMPERATURE DISTILLATION AND GASIFICATION OF PULVERIZED COAL, REMOVING THE ASH AT GAS PRODUCER.

forming substances are physically detached from the hydrocarbon combustible matter; the second, that when pulverized coal is in water suspension, the wet ash particles will not combine with oil; the third, that the wet coal particles, together with a given amount of oil, when suitably agitated, will combine into an oil-coal amalgam substantially free of both water and detached ash matter.

The separation of the amalgam "caviar," or spheres, from the water and released ash is merely a matter of straining.

The machinery and equipment used consist of pulverizers, agitating boxes and screens. The process is continuous and requires only attendant labor.

Amalgam, as commercially known today, is an agglomeration of small spheres of purified coal particles 80%, oil 15%, water 5%. It is called a "plastic fuel." The characteristics of amalgams vary according to three variables: the class of coal used, the fineness of the coal particles and the type of oil.

The ordinary commercial amalgam as known today consists of both anthracite and bituminous coals combined with ordinary fuel oils. These amalgams have been used for boiler firing, domestic uses, gas and coke making, but are now principally used as a prepared raw material for the manufacture of Superfuel, which is a smokeless, clean fuel, made by first molding or shaping the amalgam, and then baking same at low temperatures in the presence of a small amount of oxygen until the product is both hard and clean. Superfuel is a full anthracite equivalent, possibly sufficiently well known now not to warrant further description, except to say that when made from anthracites petroleum fuel oils are used to make the amalgam, and when bituminous coals are used the coal is first distilled and the amalgams made with the carbonized coal powders and the oils derived therefrom.

A commercial amalgam and superfuel plant is now in operation at Providence, Rhode Island, converting Rhode Island anthracites into domestic solid superfuel, which is the full equivalent of prepared sizes of Pennsylvania anthracite.

The combined Rhode Island and Massachusetts area of anthracite coals cover 600 square miles—slightly larger than the total area of Pennsylvania anthracites. This coal is not commercial in its raw state because of 30% ash, high density, low hydrogen content, and a physical property of breaking into a major percentage

of fines when mined. The coal area is now brought into commercial and competitive value by converting same to amalgam and superfuel.

At LaPugnoy, France, the Société des Combustible Purifies has an amalgam plant with a capacity for making 400 tons per twenty-four hours. The superfuel step has now been perfected and the retorts for converting the entire amalgam production are being installed. The bituminous coal is pulverized and then de-ashed by amalgamation. The amalgam is first dried of water content, then briquetted with Belgian rolls, then baked in retort pots with superheated steam. The oil thus derived is used to make the amalgam. The oil fractions distilled from the amalgam are by-product, low temperature oils from coal. No petroleum is used. About forty gallons of oil are used to make a ton of amalgam and fifty gallons recovered, part of which is from the oil and part from the raw coal. This operation demonstrates the utilization of bituminous coals in the manufacture of anthracite equivalent, the coals being first de-ashed and then made into smokeless fuel of uniform and desired sizes and shapes.

The amalgamating process is about to be applied to several other uses; one is to make a liquified amalgam by first pulverizing the coal to much finer sizes than the ordinary 200 mesh. Amalgams made with coal pulverized finer than 350 mesh will take oil and retain same in equal weights with the coal, and the product is a liquid emulsoid. It will pump and handle similar to ordinary fuel oils, therefore it becomes a full fuel oil substitute, both for steam raising and cracking for motor fuels. Another new use is to purify coal by amalgamation using a light boiling oil such as kerosene or gasoline, and then evaporating the oil so as to have the purified carbon dust.

Internal Combustion of Purified Carbon Dust

It has been disclosed that coal can be pulverized to 300, 400, 500 or even 1000 mesh, and that its impurities can be largely removed. It has been pointed out that finely pulverized coal can be made to flow and answer the laws of liquids. It has long been known that coal dust, if purified and properly introduced, is a successful internal combustion fuel. Dr. Diesel originally intended coal dust to be used in his engine. An accompanying letter from

the Bureau of Standards to the War Department describes a successful operation of actually introducing coal dust into a combustion cylinder operating under the constant pressure cycle, setting up the continuous combustion of the coal at a pressure of 50 pounds per square inch and regulating the temperature of the resulting gases.

Powdered coal, as herein discussed, is just as well suited to constant pressure cycle engines as liquid fuels. At similar working pressures, the constant pressure cycle will deliver a higher attainable thermal efficiency than either the Otto or the Diesel cycle.

A Specification Anti-Detonating Powdered Coal Fuel

It is proposed and under way to present a specification coal powder fuel that is actually fitted for adaptation to both Diesel and Otto cycle engines. This fuel will be made to meet varying and special requirements. It will have the anti-detonating characteristics and a controlled rate of flame propagation, because in the manufacture of this fuel there will be certain percentages of sizes of coal that measure down in the micron sizes, others of 1000 mesh, others of 500 mesh. The volatile of the coal will be adjusted to suit, and the densities of the particles will be selected and controlled. It will be a prescription fuel to meet any and all requirements.

Because coal can be purified; because it can be pulverized to minute sizes; because it can be distilled at high thermal efficiencies to produce oil, gas and carbonized powder; because it can be made to flow and to pump; because it responds to the most efficient methods for the creation of mechanical energy, the world may look forward with confidence to a new "Age of Coal," greater and more permanent.

POWDERED COAL FOR POWER PURPOSES

RECENT DEVELOPMENT IN BURNING POWDERED COAL UNDER STEAM BOILERS

By HENRY KREISINGER

Research Engineer, Combustion Engineering Corporation

This paper deals with the development of water or steam cooled furnaces for burning powdered coal in steam generating units, and points out that these water and steam cooled furnaces make it possible to take full advantage of turbulent mixing in the combustion space which is necessary for high rates of combustion.

BURNING POWDERED COAL IN REFRACTORY LINED FURNACE

The early installations for burning powdered coal under steam boilers had refractory lined furnaces which were designed and constructed along the same line as the stoker furnaces of that time. The main difficulties encountered when burning pulverized coal in such furnaces was the slagging of the ash and rapid erosion of the fire brick furnace lining. The ash fused and accumulated in molten or semi-molten condition at the bottom of the furnace and was very difficult to remove either hot or when cooled. The removal of such slag required much hard labor and caused frequent outage of the boiler from service.

EROSION OF BRICK LINING

The ash was sprayed on the hot refractory walls and ran down in molten condition, eroding the brick and washing it to the bottom of the furnace. Under such a condition the fire brick lining wasted away rapidly and required frequent repairs. The washing away of the brick lining was particularly rapid if the flames were allowed to impinge on it. In order to prevent the impingement of the flames the walls were moved out of the flame by making the furnaces larger than was necessary for merely complete combustion.

EFFORT TO PREVENT FLAME IMPINGEMENT

In the effort to prevent the impingement of flames on the fire brick lining the turbulence of the furnace gases was limited to the minimum.

The lack of sufficient turbulence made the process of combustion rather slow, so that only a small amount of coal could be burned per cubic foot of combustion space. Usually the rate of combustion was limited to an average of about two pounds of coal per cubic foot of the entire combustion space, or the rate of heat liberation of about 25,000 B.t.u. per cubic foot per hour. This average was low because in the effort to prevent the impingement of the flame against the furnace lining the combustion space near the walls was very little effective.

Effort to Produce Suitable Refractory Hollow Walls

Efforts to produce refractories at reasonable cost that would resist the erosive action of the molten ash met with little success. The composition of coal ash varies so much that it is difficult to get refractory material that would resist each variation in the ash composition. Air cooled hollow walls gave some relief, but the problem of erosion was not completely solved.

Lack of Mechanical Strength of Refractory Walls

As the size of the steam generating units was rapidly increasing and the furnace walls had to be built very wide and high, the furnace designer was faced with the problem of making the walls mechanically strong so that they would not collapse before they were worn out by the erosion of molten ash. The expansion and contraction on such large walls is great, so that it is difficult to provide slipping joints on such structures.

Water Cooled Furnaces

During the last three or four years the furnace designers gradually came to the realization that the right way to build a furnace for burning powdered coal was to make the furnace walls of water cooled or steam cooled surfaces, in other words, to build the boiler around the furnace. Such metallic walls would be very durable and strong and would also absorb a large amount of heat, thereby relieving the boiler proper of much of the work, and particularly they would relieve the first row of tubes of the excessive heat to which it

was exposed in the refractory furnaces. This is no small consideration these days when boilers are operated at high ratings.

Water Cooled Furnaces Can Be Worked at Higher Rating

A furnace with water cooled walls can be worked at much higher average rate of heat liberation, because there is no danger from erosion caused by the impingement of flames. Intense turbulence of the furnace gases can be used, and all of the combustion space made effective to the full extent. In addition to the fact that the entire space can be made fully effective, intense turbulence produces very effective mixing and causes more rapid combustion so that the average rate of heat liberation can be increased up to 40,000 B.t.u. per cubic foot of combustion space per hour, with nearly complete combustion. This increased rate of heat liberation permits the use of smaller furnace than was possible with refractory walls.

Intensive Mixing in Furnace Important

Intensive mixing in the furnace is by far the greatest factor in the promotion of rapid combustion. It brings the oxygen and carbon together so they can combine. When the two are once brought together at the ordinary furnace temperature the chemical combination is almost instantaneous. In other words, the rate of combustion is determined by the rapidity with which oxygen and carbon are brought together and not by the speed with which they combine when once brought together.

High Temperature

The particles of powdered coal although small in size, when compared with the oxygen molecules are still very large. A very large number of oxygen molecules must be brought in contact with the coal particles before they are completely burned. The surface of the particles is rather small, so that only a small number of oxygen molecules can be brought in contact at a time. The products of combustion must be continually removed from the surface in order that a contact with fresh oxygen molecules can be made. Intensive mixing helps to remove the products of combustion and bring fresh oxygen in contact with the surface of the coal particles.

The temperature above the limit of ignition is of minor importance because it affects directly the rate of chemical combination

of oxygen and carbon when the two are brought together. It does not affect materially the mixing or the bringing of the oxygen and carbon together.

It is frequently observed that rapid combustion is accompanied by high temperatures, and the conclusion is sometimes drawn that the rapid combustion is caused by high temperatures. However, the true sequence of the cause and the effect is this: intense mixing causes rapid combustion and rapid combustion causes high temperatures.

With the usual rates of combustion used in steam boiler practice there is very little danger that water cooled furnace walls would cause incomplete combustion by excessive cooling of the flame. The temperature of the flame is always high enough for anything to burn that is burnable, as long as the supply of air is sufficient and the air mixes properly with the coal particles.

Preheated Air and Its Effect on the Furnace Design

Another factor contributing to the demand for the water cooled furnace walls is the preheating of the air used for combustion. The practice of the bleeding of turbines for heating feed water is growing rapidly. This practice limits the use of the economizer and its place is taken by the air heater. With the use of the preheated air the furnace temperature is higher and, therefore, the wear on the refractory furnace walls greater.

Water and Steam Cooled Furnace under High Pressure Boiler

Fig. 1 shows the water and steam cooled furnace of a high pressure boiler at the Lake Station of the Milwaukee Electric Railway and Light Company. The front wall consists of water cooled fin tubes. The arch is protected by plain tubes. The side walls are made of the radiant type of superheater and the back of the radiant type reheater. The bottom is cooled with a water screen and the tubes of the boiler form the roof of the furnace.

Steam is generated at a pressure of 1200 pounds and superheated to a temperature of 720° F. It is then expanded in a high pressure turbine to 300 pounds pressure and 420° F. temperature. The steam from this high pressure turbine is passed through the reheater where it is heated to 720° F. and discharged into the main steam line of the plant and is used in the large turbines.

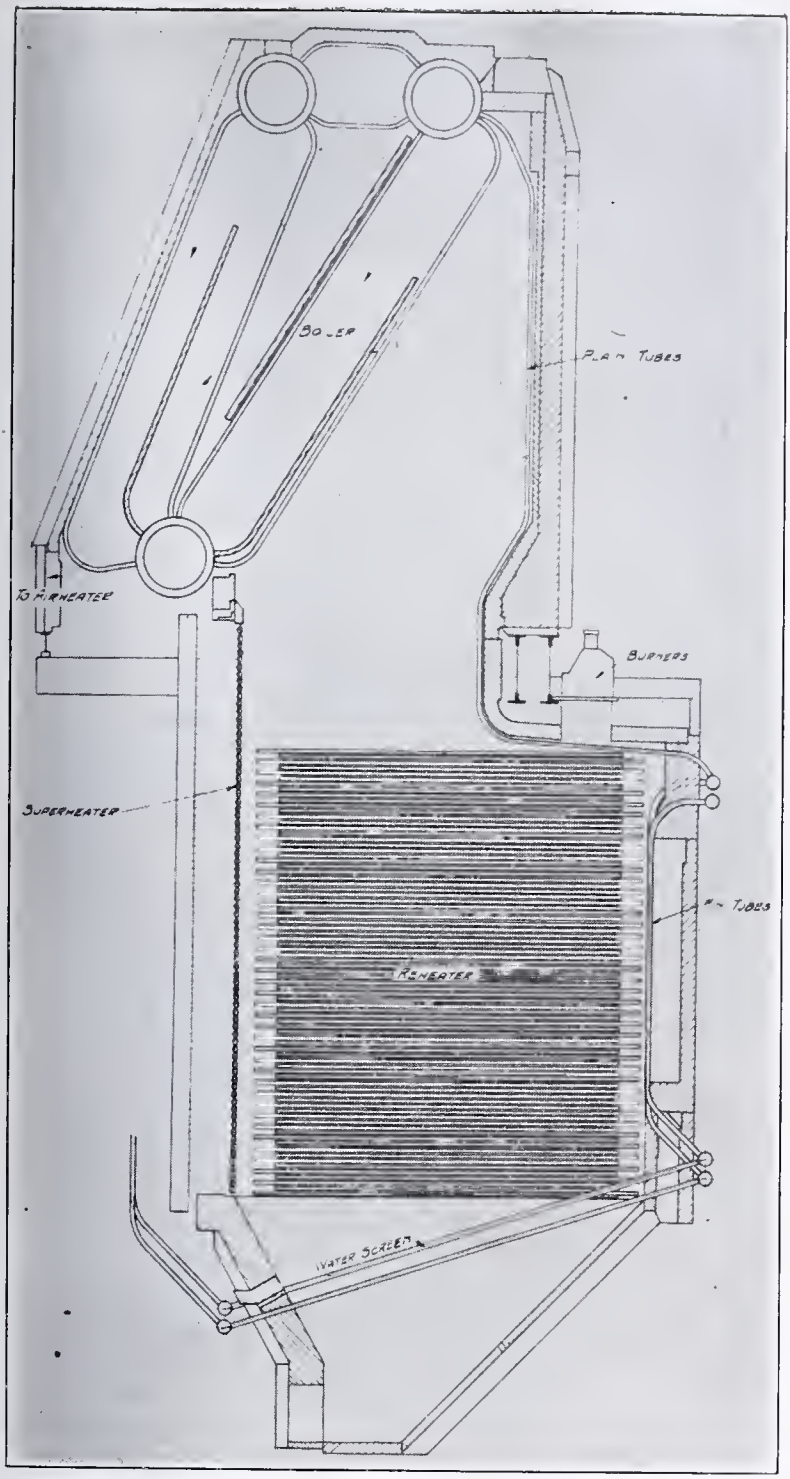


FIG. 1. TWELVE HUNDRED POUND PRESSURE UNIT, LAKESIDE STATION, THE MILWAUKEE ELECTRIC RAILWAY AND LIGHT COMPANY. STERLING TYPE BOILER.
Superheater in back wall of furnace, reheater in side walls. Fin tubes in furnace front wall, plain tubes under arch and in front wall above arch.

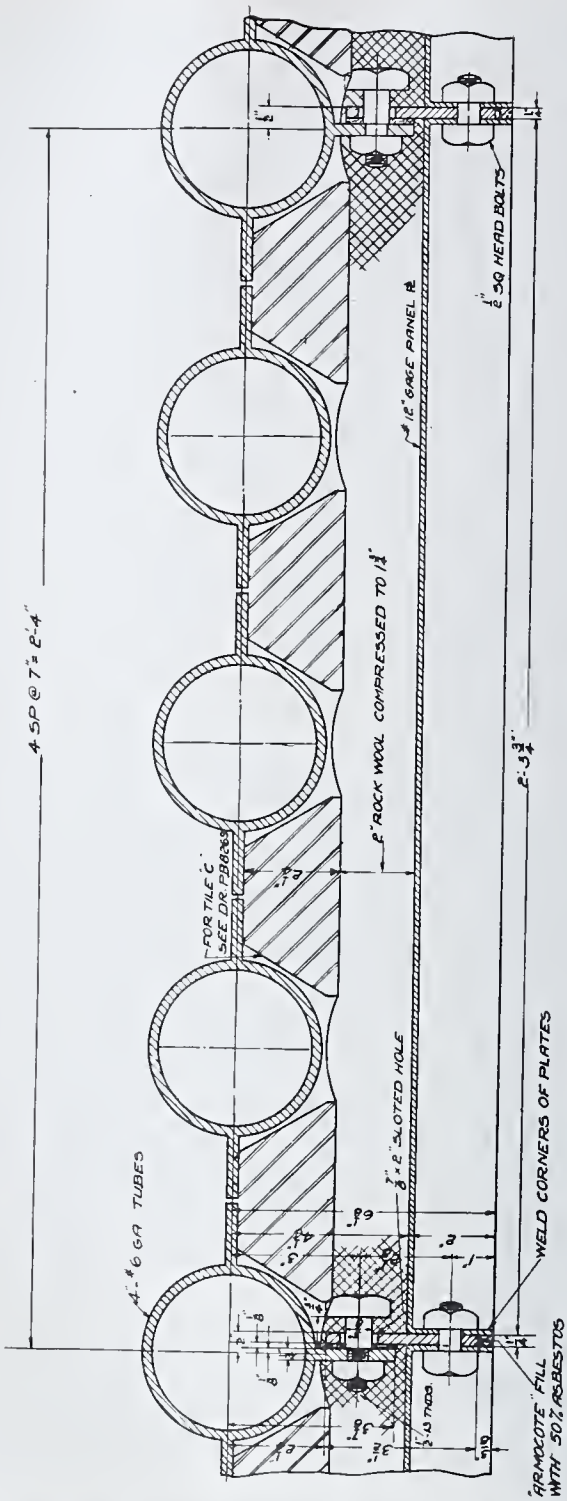


FIG. 2. FIN TUBES AND THEIR ARRANGEMENT TO FORM CONTINUOUS WATER COOLED METALLIC WALL.

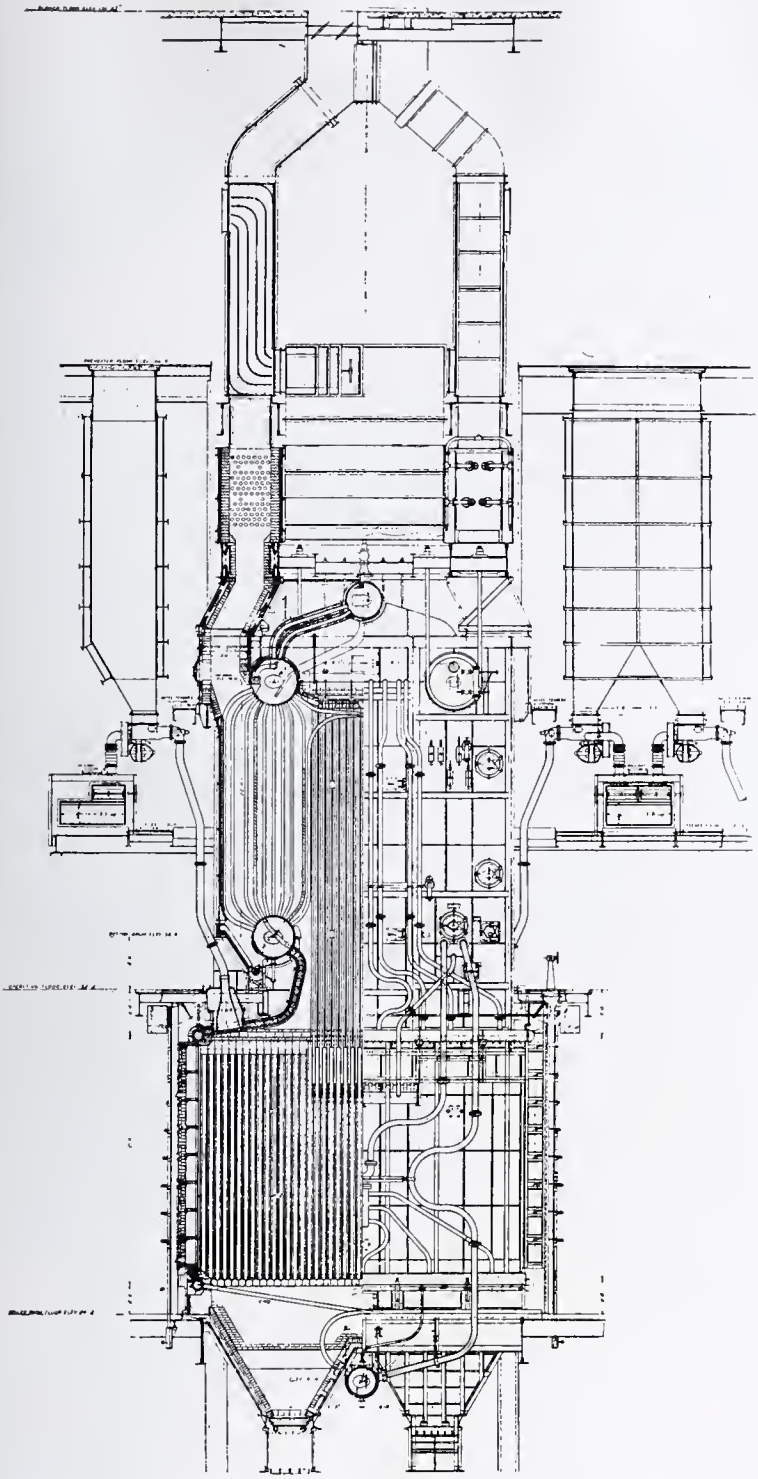


Fig. 3. Steam Generating Unit With Water Cooled Furnace Walls, 35th Street Station, New York Steam Corporation. All Furnace Walls are of the Fin Tube Design.

The capacity of the boiler is 240,000 pounds of steam per hour. The heating surfaces are as follows:

Water heating surface in furnace	1,544 sq. ft.
Water heating surface of boiler	28,532 sq. ft.
Total water heating surface	30,076 sq. ft.
Superheating surface	930 sq. ft.
Reheating surface	933 sq. ft.
Total heating surface in furnace	3,407 sq. ft.
Air heating surface	40,320 sq. ft.

Powdered coal is fired through 12 burners vertically downwards. Primary air is supplied under pressure of 15 inches of water at a temperature of 300° F. Secondary air is supplied through burners and through ports in the front wall at a temperature of about 500° F. and a pressure of about half an inch of water.

FIN TUBE

The term fin tube is applied to a special design of tube consisting of a standard size and gauge tube to which have been welded two flat steel bars, one on each side of the tube. A number of such tubes when rolled into a header in a single row make a practically continuous surface, as shown in Fig. 2. The flat steel bars are 1½ inches wide and ¼ inch thick. One of the flat surfaces is exposed to the radiant heat from the flame. This heat is transmitted by conduction to the tube and to the water inside of the tube.

WATER COOLED FURNACE UNDER A STEAM HEATING BOILER

Fig. 3 shows a completely water cooled furnace of the 35th Street Station of the New York Steam Corporation. All four walls of the furnace are of the fin tube construction. The furnace bottom is cooled by a water screen, and the furnace roof is formed by the boiler tubes. The arrangement of the heating surfaces is as follows:

Furnace surface:

Side walls in furnace	1,336 sq. ft.
Side walls between boiler tube banks	666 sq. ft.
Front walls	942 sq. ft.
Arches	500 sq. ft.
Water screen	688 sq. ft.
Total surface in furnace	4,132 sq. ft.

Boiler surface	10,802 sq. ft.
Total water heating surface	14,802 sq. ft.
Superheating surface	None
Economizer	10,802 sq. ft.
Air heater	46,800 sq. ft.
Total surface	71,682 sq. ft.
Working pressure	275 pounds

Coal is fired vertically downwards on two sides of the furnace through twelve burners located in the arches. Secondary air is supplied through the burners and through air ports in the two front walls under a pressure of 1 to 2 inches and preheated to about 500°F.

The effective combustion space is 19,000 cubic feet. Normal capacity of the unit is 340,000 pounds of steam per hour.

WATER AND STEAM COOLED FURNACE OF THE FORDSON PLANT

Fig. 4 shows a water cooled furnace of the Fordson Plant of the Ford Motor Company. The furnace is somewhat similar to that shown in Fig. 3. It differs from it in that the side walls between the two banks of boilers tubes and the two front walls are not water cooled, and that part of the cooling surface in the furnace side walls consists of a radiant type of superheater. The superheating elements of this radiant superheater are placed between plain water heating tubes.

Some convection type superheating elements are also placed in between the first banks of the boiler tubes.

The various types of the heating surfaces are as follows:

Furnace surface:	
Water heating surface in side walls	1,554 sq. ft.
Water heating surface in arches	750 sq. ft.
Water screen	710 sq. ft.
Superheating radiant surface in side walls	1,100 sq. ft.
Total furnace surface	3,014 sq. ft.
Boiler surface	26,470 sq. ft.
Total water heating surface	29,484 sq. ft.

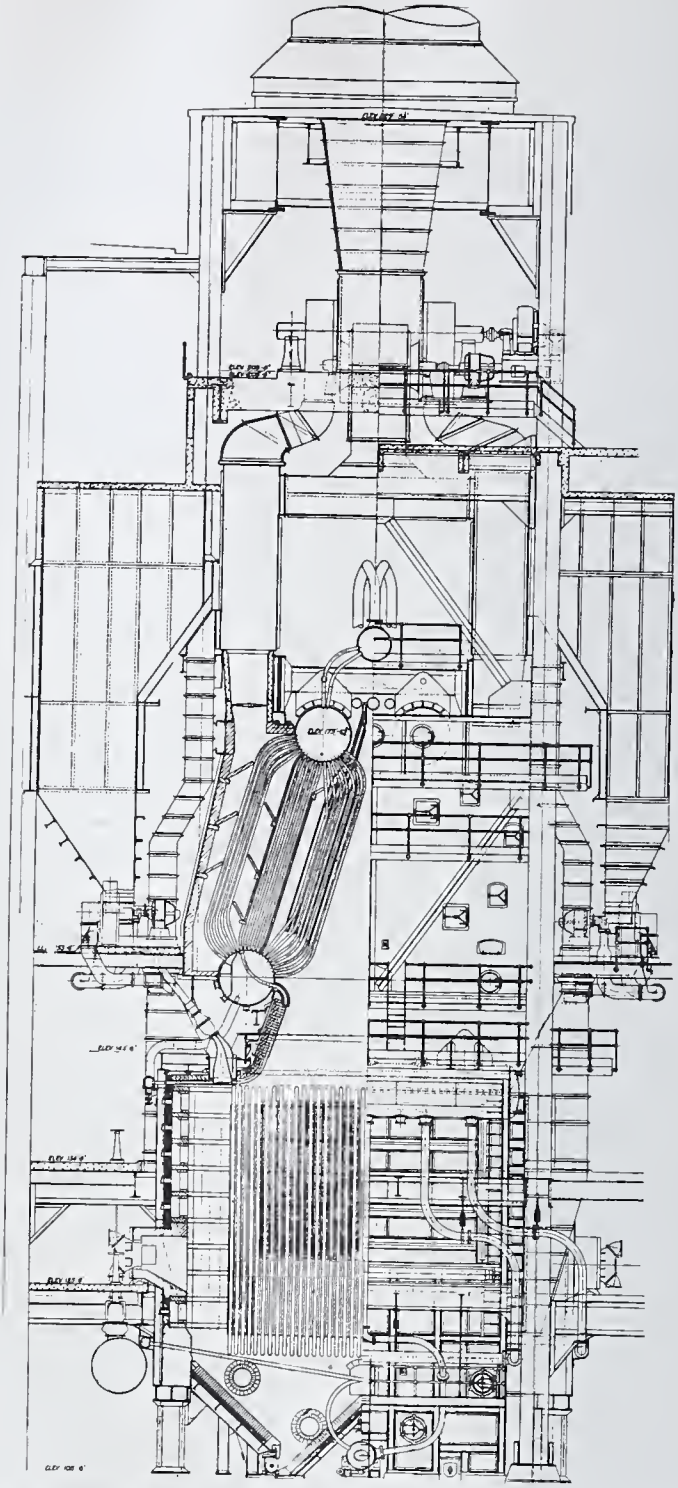
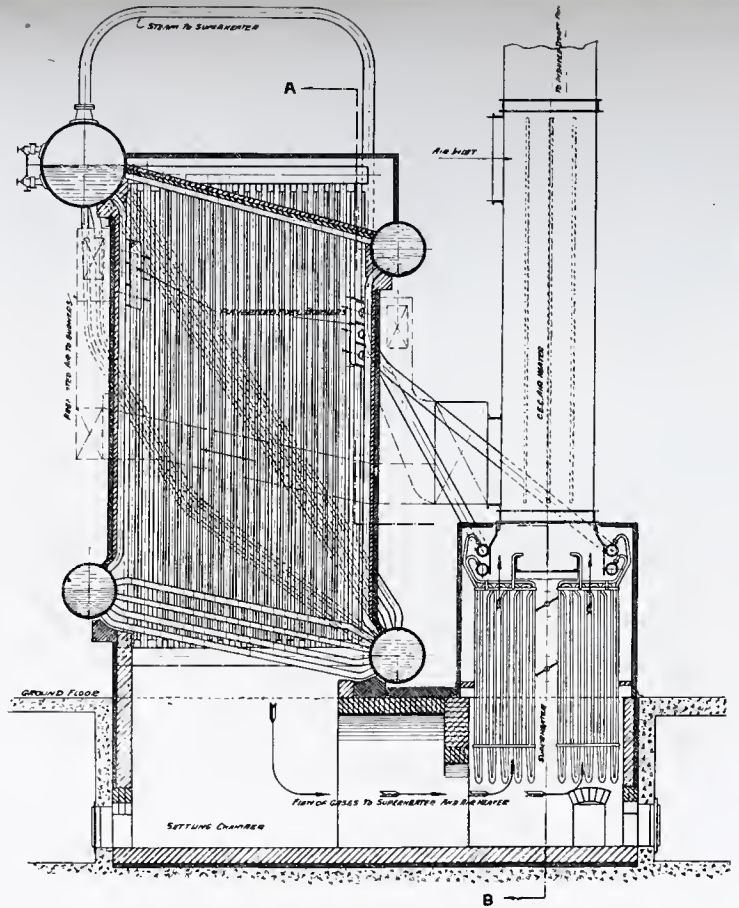
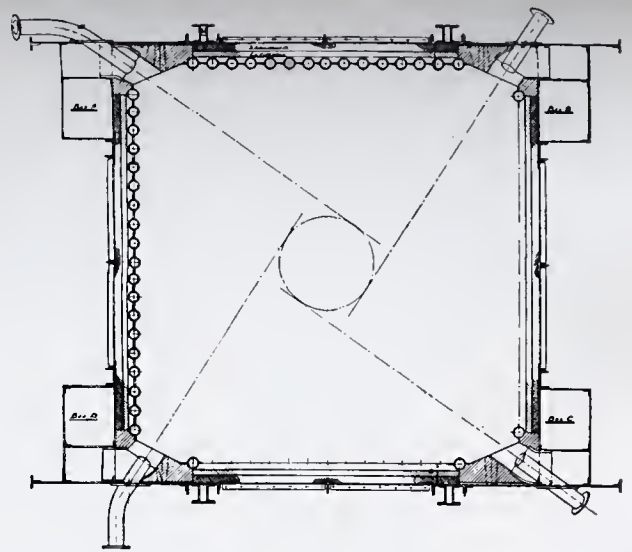


Fig. 4. Steam Generating Unit With Water and Steam Cooled Furnace Walls, Fordson Plant, Ford Motor Company. Fin Tubes and Radiant Superheater in the Side Walls. Convention Superheater in First Bank of Tubes of Boiler. Arches Protected With Plain Tubes



Side Elevation



Plan View

Fig. 5. Wood's Steam Generator, Taylor Brothers Steel Plant, Manchester, England.

Convection type superheater..... 3,520 sq. ft.

Total superheating surface..... 4,620 sq. ft.
Air heating surface.....39,700 sq. ft.
Working pressure . . ..300 pounds

Powdered coal is fired vertically downwards from two sides of the furnace through 24 burners located in the arches.

Normal capacity of unit 340,000 pounds per hour.

Peak capacity 480,000 to 500,000 pounds per hour.

Effective combustion space 22,000 cubic feet.

Wood's Steam Generator

The foregoing three furnace designs show to what extent water or steam cooled surfaces are applied in the construction of metallic furnaces for standard types of boiler. Fig. 5 shows a special design of a steam generating unit in which a large part of the boiler has been built around a furnace of a suitable size and shape. The furnace is nearly square in cross section. Its height is about twice its width. All four walls are of the fin tube construction. The roof is made of plain tubes supporting a layer of tiles. At the bottom of the furnace is a bank of tubes consisting of four horizontal rows of water tubes.

Powdered coal is fired through eight burners, two in each corner near the top of the furnace. The mixture of coal and primary air is projected nearly horizontally somewhat towards the center of the furnace in such a way that the streams of the mixture are tangent to a circle about 3 feet in diameter. Preheated secondary air is supplied under pressure of 1 to 2 inches of water around the burners about in the same direction. The mixture of the coal and air travels in a helical path downwards and the products of combustion leave the furnace through the bank of tubes at the bottom of the furnace. The helical flow of the mixture through the furnace causes intense turbulence, thus causing a rapid combustion and high flame temperature, permitting rates of combustion resulting in the liberation of 40,000 B.t.u. per cubic foot of combustion space per hour. Turbulence of such intensity could not be attempted in a refractory lined furnace without rapid destruction of the refractories.

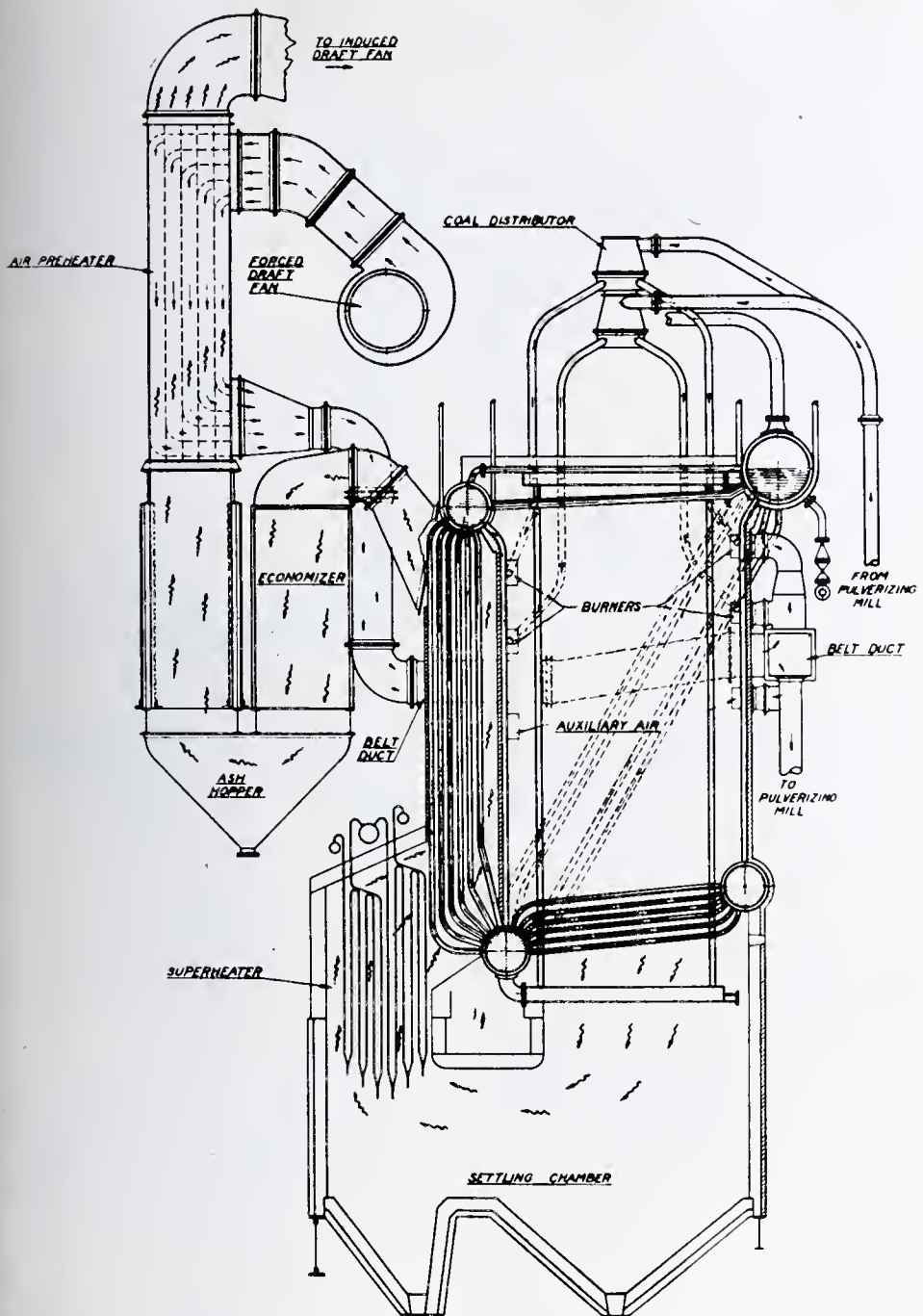


FIG. 6. STEAM GENERATER, CALUMET STATION, COMMONWEALTH EDISON COMPANY OF CHICAGO. ALL FURNACE WALLS OF THE FIN TUBE CONSTRUCTION.

After the products of combustion pass through the bank of tubes at the bottom of the furnace they turn upwards and flow through the superheater. After that they may flow through an economizer into an air heater, or, if the economizer is omitted, directly into the air heater. The amount of water heating or air heating surface placed in the path of the products of combustion depends on the temperature to which the gases are desired to be cooled when they leave the steam generating unit.

Steam Generator of the Calumet Plant

The steam generating unit shown in Fig. 6 has been designed for the Commonwealth Edison Company of Chicago for their Calumet Station. The heating surfaces of this unit are as follows:

Water heating surface:

Rear bank of tubes	3,637 sq. ft.
Side walls	1,710 sq. ft.
Roof	254 sq. ft.
Bottom bank of tubes	1,375 sq. ft.
Total water heating surface	6,976 sq. ft.
Superheating surface	3,000 sq. ft.
Economizer	5,250 sq. ft.
Air heating surface	25,200 sq. ft.
Steam pressure	360 lb. gauge
Effective combustion space	5,000 cu. ft.
Normal capacity of unit	125,000 lb. per hr.
Peak capacity of unit	150,000 lb. per hr.

Rate of Heat Absorption in Furnace

The rate at which the water heating surfaces in the furnace absorbs heat varies from about 20,000 to 60,000 B.t.u. per sq. ft. per hour and depends on the rate of heat liberation per sq. ft. of surface exposed to radiation. Approximately about one-half of the total heat absorption by the water takes place in the furnace.

Burner for Producing Turbulence

The importance of intense turbulence in the combustion of powdered coal is generally recognized and the designers of coal burning equipment strive to obtain it in various ways. Fig. 6 shows an equip-

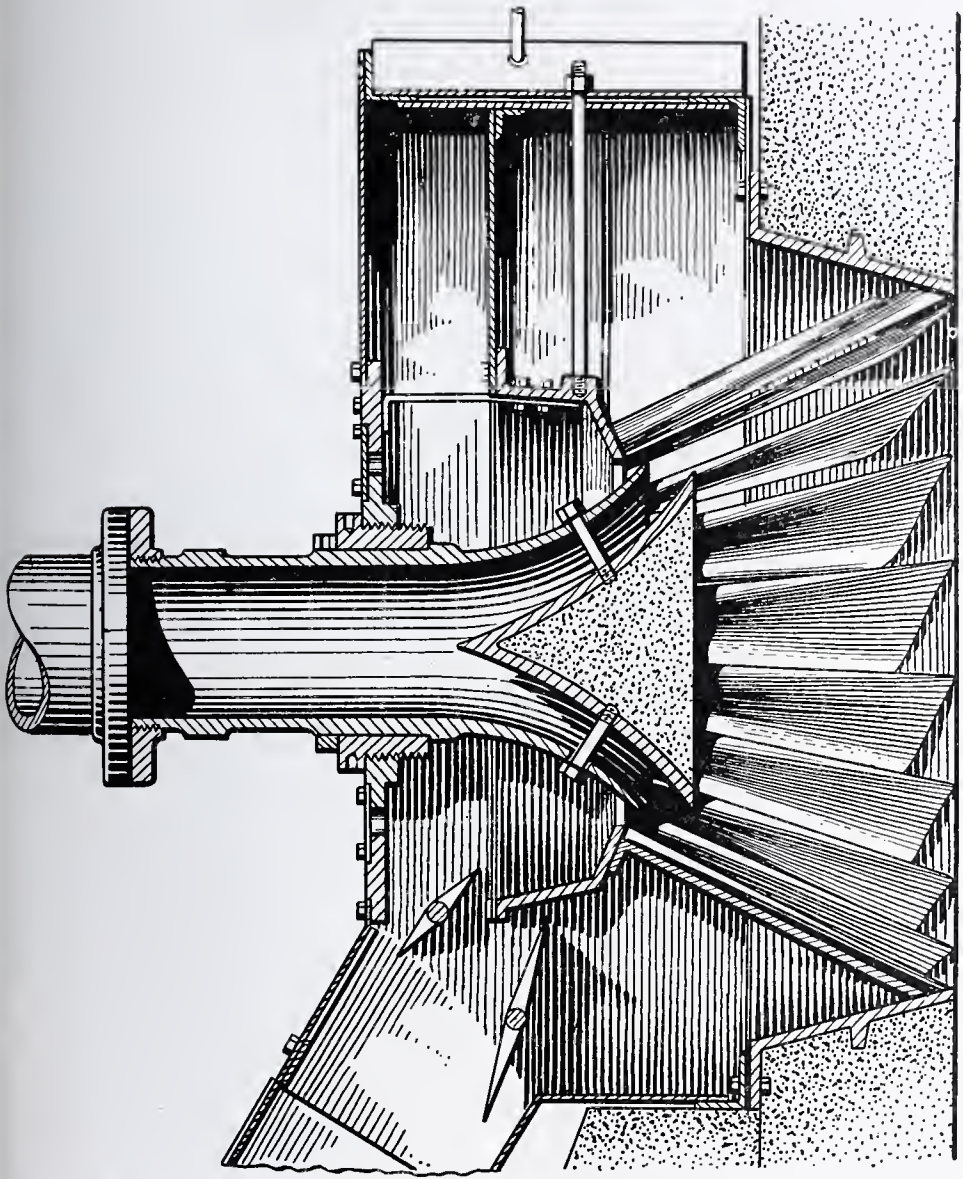


Fig. 7. Couch Burner for Turbulent Mixing in Furnace.

ment in which the turbulence was obtained by four streams of the mixture of air and coal at right angles to each other. Similar turbulence can be also obtained by a single burner in which a larger number of air jets, or jets of a mixture of coal and air, are forced into the furnace at comparatively high velocity in such a way as to start a rotary motion of the mixture. If such a burner is properly located in the furnace so that the flame is confined by the furnace walls, the rotary motion may continue for some distance in the furnace and results in good mixing. A type of this burner is shown in Fig. 7. This burner is designed along the line of an oil burner. A mixture of powdered coal and primary air enters in the center of the burner and is spread into a cone by the conical core placed in the bell shaped end of the coal pipe. A number of secondary air jets enter between the fan shaped blades and impinge nearly at right angles against the cone of the coal, and start rotary motion. This type of burner is meeting with considerable success. When properly placed so that the rotary motion is maintained some distance in the furnace, furnace rates of combustion up to 35,000 B.t.u. liberated per cubic foot per hour can be obtained.

MOUTH OF MINE POWER STATIONS

By Geo. A. Orrok

Consulting Engineer, The New York Edison Co.

For many years it has been customary for scientists and publicists to insist that power should be generated at the mine mouth, thus saving the enormous freight bill which the use of coal away from the mine necessitates. This has been the subject of newspaper articles, papers in the scientific journals, presidential addresses before learned societies, and at times has even taken on a political aspect. Most of these statements or articles have been written by people who were not in the power business and had a more or less imperfect knowledge of the demand of an electricity supply system. One noted scientist even proposed that the mine should be sealed, set on fire, and that air should be pumped into the mine, the carbonic oxide resulting being used in gas engines or being transmitted to a distance through pipes. Most of the proposals, however, have considered small sized aggregations of power because mine outputs are usually under 2,000 tons per day. In this country a mine producing 4,000 tons continuously per day is a very large mine. In England and on the Continent such mines are unknown except in the brown coal field, where open mining is practiced. Large aggregations of power under one roof generating from three to six million k.w. hours per day require large supplies of coal and continuity of service which has been best secured by a number of separate supplies.

The problem of the location of a central station, whether at the mine mouth or at a distance from the coal fields, may be considered as composed of the evaluation and summation of three factors. Many solutions are thus possible. There may be several best solutions or possibly only one. The first of these factors may be considered under the head of markets. Nearness to a market implies short transmissions, small losses and therefore smaller investment and operating cost. Adequate water supply comes next. Ferranti considers this factor of prime importance since from 500 to 1000 tons of water are required for each ton of coal burned in the station if good thermal economy is to be secured. If the supply of water

is not adequate, spray ponds or cooling towers must be used, the installation must be larger due to loss of vacuum and the fuel used must of necessity be much greater. Next to markets and water supply comes a certain and adequate fuel supply, without which no production of power is possible. Water supply figures are well known, transmission costs are comparatively stable, but the quality and price of fuel at any given plant has varied over a wide range in any given period of years in the past. What it will do in the future no man can tell. We have thus a problem involving the summation of three factors in which the costs of transmission to markets, the cost of the supply of water and the cost of fuel must be so chosen as to insure a minimum delivery cost at the point of use.

Transmission costs are well known and have been published so often that they may be said to have been standardized. In my discussion of Mr. John R. Freeman's paper in Volume 45, page 559, of the 1923 Proceedings of the A. S. M. E., I have endeavored to evaluate these costs. Klingenberg in "Large Power Stations" has perhaps a better statement, but the most recent study is by Colonel Kelly in a report of the Federal Power Commission to Secretary Hoover. Some of his curves have been reproduced in the report of the North Eastern Super Power Committee, brought out a few months ago. It will be noted that his figures in the usual range of load factors vary between 1½ mills at 100 miles distance to about 3 mills at 300 miles distance. Transmission costs, however, should be avoided and wherever possible the station should be located near the center of distribution.

The flow of our larger rivers has been measured by the Water Supply Division of the Geological Survey and its publications enable us to determine the available supply of water of most of our rivers and creeks. Wherever possible the station should be located where reasonably cool water in adequate quantity is available, either on a river with a good average flow or else on a large lake or arm of the sea. This reduces the water cost usually to its lowest limits. When this is not possible, spray ponds or a cooling tower installation have been used. Spray ponds require a very large area for a small effect; cooling towers are usually a much better investment than the spray ponds, especially when larger amounts of power are being considered, but no station using cool-

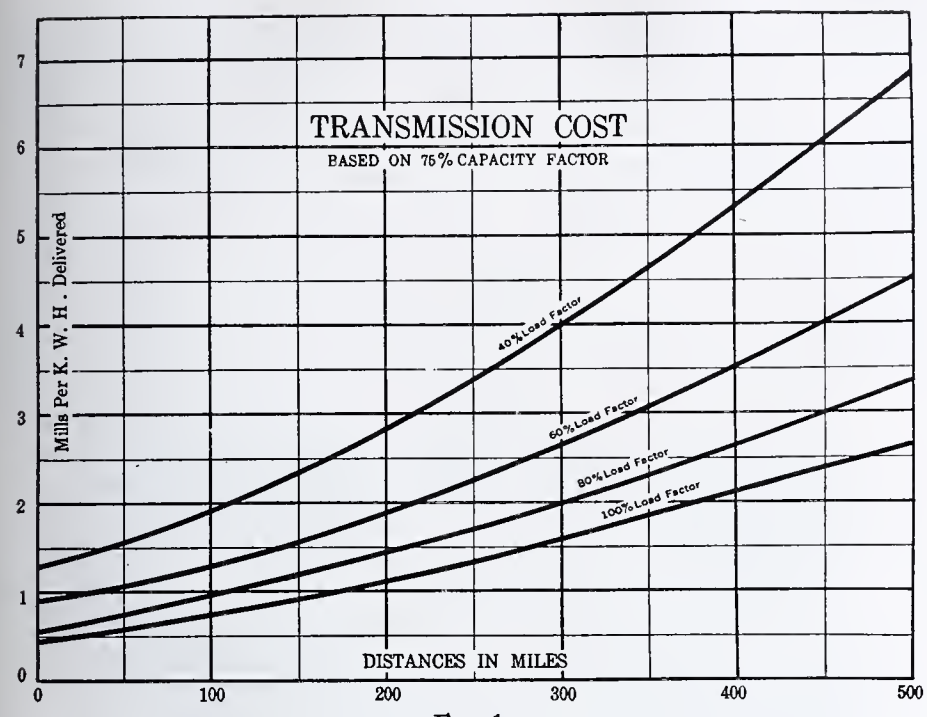


FIG. 1

ing towers to cool the condensing water has done better than about 25,000 B.t.u.'s per k.w. hour, over a year, even in Europe where the mean annual temperatures is considerably lower than in the United States. The loss of power involved is also considerable and may be as large as 10-15%. Notwithstanding this, there have been many installations using the cooling tower system with fairly good success in places where the water supply is small and the mean annual rainfall is low. The space occupied for the cooling towers is nearly if not quite as large as the station itself and the pumping heads are considerable. When we remember that in this country we have at least twenty-four power stations which are running on less than 20,000 B.t.u.'s per k.w. hour, over a year, and some on as low as 15,000 B.t.u.'s, it will be seen that artificial cooling methods should be avoided wherever possible.

Locating the central station at the mine mouth reduces coal cost to the minimum. With powdered coal firing it has become possible to obtain good efficiency with the poorer grades of fuel and a reasonable efficiency can be obtained with waste low grade fuel. It will readily be seen that the poorer the coal, i. e., the

larger the percentage of ash, water and sulphur, the larger the freight fraction becomes and a point soon arrives where the fuel cannot stand transportation charges and must be utilized at the mine or be wasted. Such is the case at Golpa, Fortuna, and Hirschfeld, in Germany, where the coal carries 55% of water and less than 40% of combustibles. As the water supply at these locations is very small, cooling towers are used and a large and costly installation is necessary for a given amount of power which has been supplemented in the case of Golpa by the new Rummelsburg Station (first section 168,000 K.W.) within a few miles of the load

FIG. 2. 100,000 VOLT INSTALLATIONS IN NORTH, SOUTH, AND MID-GERMANY
Planned Installations not shown.

center. Here plenty of condensing water can be obtained but the fuel will be costly, and the station is designed to run on somewheres between 16,000 and 17,000 B.t.u.'s per k.w. hour for a year, and the cost of current at the point of use will be lower than that transmitted from Golpa, located at the brown coal mine 75 miles away.

If sufficient water is present in proximity to the mine as at Toronto or Beech Bottom, good vacuums can be obtained and the water cost may be reduced to a minimum also. Where the market is close by as in the stations near Pittsburgh, Springdale and Colfax, the third criterion, transmission cost to market, is also satisfied and the minimum cost at the point of use is obtained.

Under the price conditions prevailing in the United States it has become increasingly evident that no cooling tower central station can be commercially successful in competition with our cheaper transmission costs. This limits the mine mouth plants to those locations where condensing water may be had in abundance and transmission costs are cheaper than coal freights to a point on a good water supply nearer the market. Colonel Kelly in a report to Secretary Hoover, before quoted, stated: "When, in addition, the difficulties

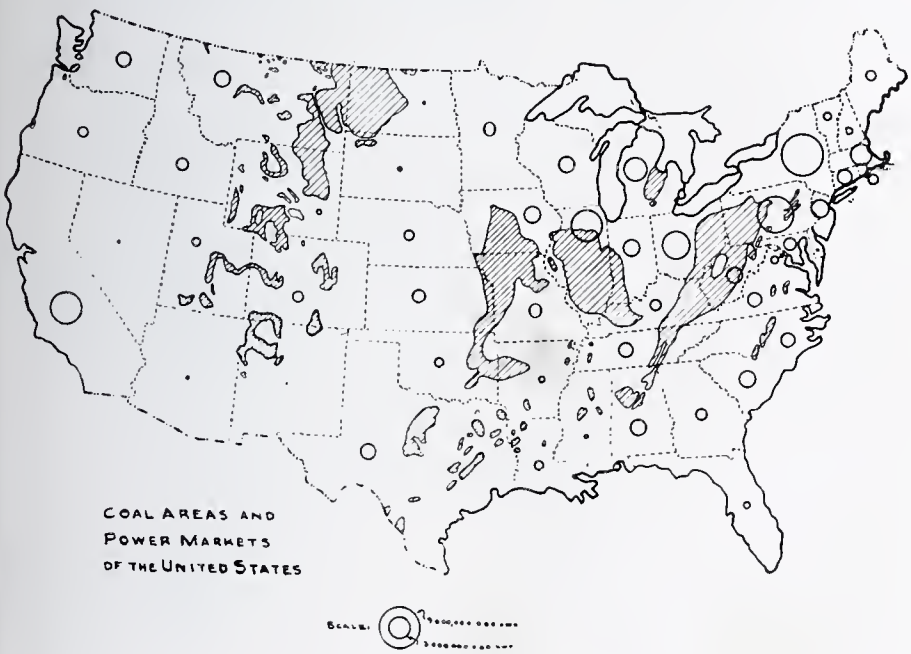


FIG. 3

incident to high-tension transmission are considered, it is safe to say that the local plant will be favored except when a material saving can be shown. Under present conditions it is not likely that power from plants at the mine will be transmitted to distances greater than 200 miles." At present writing and with his figures revised to 1926 conditions his 200 miles is probably the maximum distance at which mine mouth power may be sent and the economical distance may be very much shorter. Mine mouth locations are thus limited to those coal fields on rivers or lakes of considerable size and where the markets are within say 100 miles from the point of supply. Fig. 3 has been developed to show the coal areas of the United States, the water supplies capable of serving reasonably sized aggregations of power and the tributary district which might commercially be fed from mine mouth plants. It should be remembered that Colonel Kelly only allows a .03c differential for the Cleveland district, and Cleveland after much study has endorsed Colonel Kelly's opinion and is building their Avon Station on the water near Lake Erie, instead of going to the mouth of mine somewhat over a hundred miles away. Youngstown has a mine mouth supply from the Toronto Station, but it is probable that Cincinnati is too far away to gain advantage from such plant. Meanwhile, the location of the new Miami Fort generating station shows how carefully this subject has been studied by the Cincinnati Company. The Commonwealth Edison Company is locating their newest station on Lake Michigan instead of in the coal areas less than one hundred miles away.

Amongst the plants which are quoted as being mine mouth plants there are only a few which may logically come under this classification. Such plants as Beech Bottom, Toronto, Golpa, Springdale and a few others are actually mine mouth plants; such plants as Hauto and Saxton, where the station is located three or four miles from the mine, implies that the coal must be dumped from the mine cars into railway cars and thus transported to the station where the unloading cost is added to the haulage cost. It has always been plain that the terminal charges of these short hauls exceed 25¢ a ton, to which the actual transportation charges must be added. In general there is a definite line to be drawn between the actual mine mouth station and the station using a private railroad or the public common carriers. As

the haulage distance increases terminal charges become a smaller part of the cost and the ton mile cost of delivery becomes smaller. That these locations away from the mine are more than justified is shown by the many stations which are thus located. Cahokia, for instance, located on the Mississippi River for condensing water reasons as well as the shorter transmission, is in a position to get coal from three or four different fields, although its nearest coal supply is less than 20 miles away. A location in the coal field itself would have been almost prohibitive, due to the lack of condensing water. It should be remembered that the operating cost at Cahokia is one of the lowest in the country

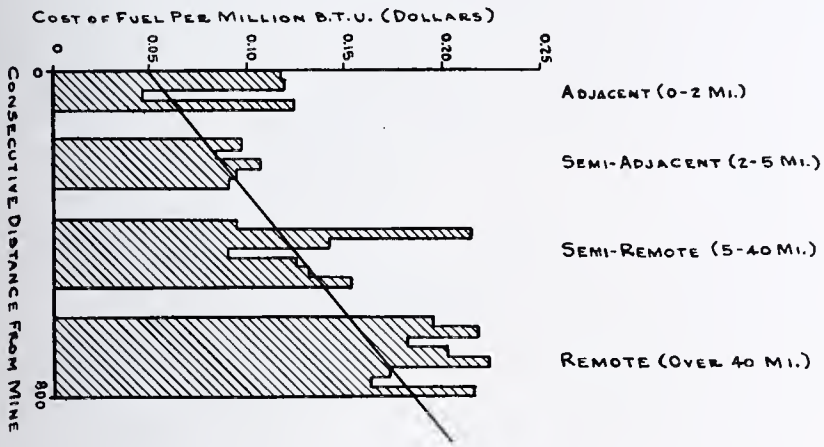


FIG. 4 COST OF FUEL FOR ADJACENT, INTERMEDIATE AND REMOTE POWER PLANTS

and compares very favorably with the other modern generating stations, whether located in the coal districts or away from the coal and in immediate proximity of good water supplies.

No discussion of this kind would be complete without considering the many suggestions and much experimental work which has been done along the lines of low temperature distillation in its connection with the generation of power. The only power plant in this country where this has taken definite form, however, is the new installation of the Milwaukee Railway Light & Power Co., which is just starting up, and to which reference will be made in one of the other papers. The combination of a distillation system turning out as a main product a good fuel for steam generation and supplying valuable by-products which can be sold, is an ideal greatly to be desired. The difficulties in the way of developing a low temperature distillation system, which is

a continuous 100% load factor process in connection with the generation of power, which is at the best a fluctuating 50% load factor operation, are considerable while the markets for by-products are in a most unsettled condition at the present time. With tank car gasoline quoted at 13¢, Pennsylvania crude at $3.20 per barrel, ammonium sulphate at $50, and the tar distillation companies working on about 4½¢ to 5¢ per gallon, it does not seem possible in this country to make out a commercial case at the present time. In view, however, of the

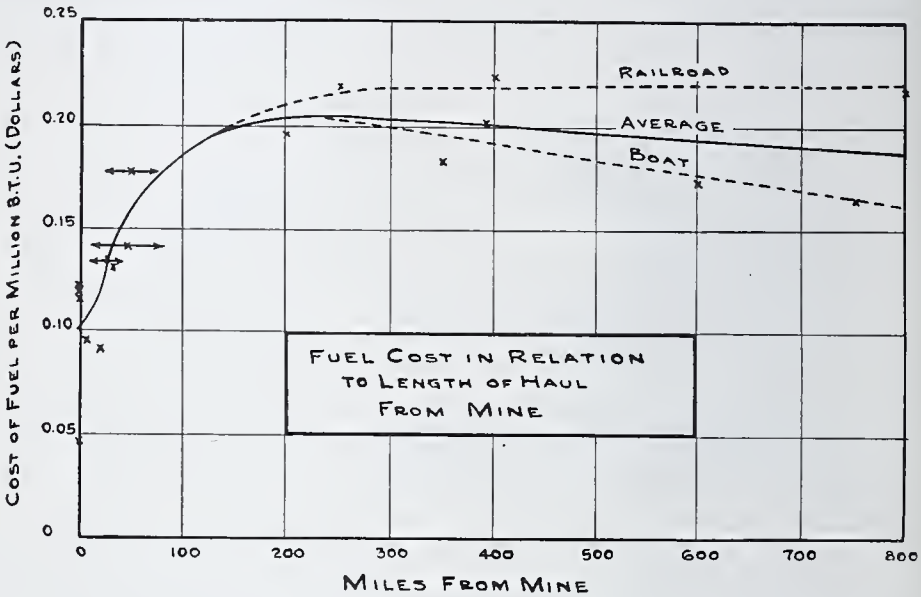


FIG. 5

restricted supplies and the enlarging use of oil products, it is only a matter of time when the supply will not be equal to the demand and the value of these products will rise to a point where commercial economies may be secured. The experimental work which is under way will be of great value in determining the course of design in the future, and it may well be that these developments may be deciding factors in the location of generating plants in certain coal fields.

CONCLUSIONS

1. The location of every generating station is a separate problem in which many factors must be taken into consideration.

2. Under normal conditions, the building of Mine Mouth Central Stations will be limited to those localities where a sufficient and reason-

ably good water supply may be obtained and where the market is sufficiently close at hand to avoid high transmission cost.

3. Poor fuels such as lignite, peat or waste coal cannot generally compete with good coals.

4. Cooling towers or spray ponds may be commercial under some conditions, but in general transmission costs are lower than cooling tower costs plus loss of station efficiency.

5. Given a sufficient return from by-products a combination low temperature distillation plant and generating station may be commercial with a high load factor market.

6. At present writing, however, no central station with restricted water supply has shown good commercial economy. Those plants using good coal, plenty of condensing water and located in proximity to markets have given the best commercial and thermal results.

THE RELATION OF THERMAL STORAGE IN BOILER AND FURNACE TO FUEL APPLICATION

By F. P. Coffin

Research Laboratory, General Electric Co., Schenectady, N. Y.

Some elementary principles concerning the thermal relations in several types of steam boilers and furnaces will be briefly reviewed. The writer has endeavored to cite examples from actual practice to illustrate certain phases of boiler evolution and this has involved a somewhat rambling treatment of the subject.

The evolution of the steam boiler has proceeded along several parallel lines, the fire-tube shell boiler and the water-tube boiler being the more important types. The shell type may be definitely subdivided along the lines of externally fired boilers and internally fired boilers. The water-tube type may be similarly subdivided, but with intermediate types in which the furnace is partially surrounded by heat absorbing surfaces. The boiler and furnace have three reservoirs for storage of thermal energy: the fuel bed, the heated refractories, and the water and metal of the boiler.

When coal is burned on the grate, the fuel bed contains a great amount of stored energy, partly in the form of sensible heat and partly in the form of the latent chemical energy of carbon and hydrogen awaiting union with oxygen.

When there is a sudden demand for steam, this stored energy is useful and may be drawn upon by merely increasing the draft.

When the demand for steam suddenly falls off, however, the control of this stored energy becomes more difficult so that the excess supply of steam generated must often be allowed to blow off thru the safety valve.

When oil or pulverized fuel is burned in suspension, the heat supply can be cut off instantly by interrupting the fuel supply, owing to the absence of energy storage in a fuel bed. In oil burning furnaces, sudden demands for steam can be readily met by increasing the rate of feeding oil to the burner. With pulverized coal the lack of energy storage introduces a limitation in the rate at

which the fire may be brought up without smoking, owing to the slower burning of the fuel at the lower temperatures which exist in the furnace bottoms after a period of low firing. After making allowance for this limitation, we may say that controlability is one of the most valuable features in the use of mobile fuels, such as gas, oil, or pulverized coal.

In externally fired boilers, the furnace walls contain extensive refractory surfaces operating at temperatures approaching that of the fire. The temperature of the refractories and of the fuel bed is so much higher than the temperature of the boiler that they act as reservoirs of heat long after an effort has been made to interrupt the heat supply. Radiation is emitted in proportion to the difference of the fourth powers of the absolute temperatures of the furnace walls and of the boiler. In spite of the high rate of radiation, the furnace walls contain so much stored heat that they require a considerable time to cool.

The Scotch marine boiler may be taken as a typical example of the internally fired shell boiler. When coal is burned on the grate, the refractories are usually limited to a low bridge wall for maintaining combustion in the distilled gases by means of radiant heat from the firebrick.

When the Scotch boiler is fired with oil, the burner is surrounded by a short refractory combustion chamber. The radiant heat from the flame maintains the walls of this chamber at an incandescent temperature and the heat radiated back initiates and maintains combustion in the cooler base of the flame. Aside from the small ignition chamber and bridgewall, no reservoir of stored heat remains after shutting off the oil. Heat transfer in the furnace is almost entirely by direct radiation from the flame to the steel walls of the cylindrical furnace and thru the metal by conduction to the water.

The application of pulverized fuel to furnaces of this type would require the addition of considerable refractory lining, and possibly an extension of the combustion chamber beyond the boiler front, in order to secure proper ignition of the fuel.

The locomotive boiler is another important example of the fire-tube shell boiler, internally fired. This boiler is required to respond quickly to demands for steam. Pulverized coal is being burned successfully in locomotive boilers by equipping the fur-

naces with firebrick arches to maintain the ignition of the fuel. It has been found practicable to burn a low grade Brazilian coal, which cannot be burned satisfactorily on grates. Pulverized coal is also being applied to locomotives in Germany.

In the fire-tube shell boiler, the heat absorbing capacity of the large quantity of water present is so great that the heat stored in the fuel bed, or even in the refractory walls of the external furnaces of land boilers, is readily taken care of.

The older and smaller types of water-tube boilers operate with less water than the shell boiler, but the quantity is still so large that at least one-half hour would be required to completely empty a boiler, at the customary rate of driving, after stopping the supply of feed water. Until quite recently, the typical water-tube boiler in power stations has been of the externally fired type. A sufficient quantity of water is present in the type having longitudinal steam and water drums to readily absorb the radiant heat from the furnace walls and fuel bed. Hence the boiler is relatively sluggish in its response to control measures when the demand for steam suddenly falls off. This sluggishness makes it somewhat difficult to apply means for automatic combustion control that will operate entirely satisfactorily.

The power plant boiler is undergoing an interesting phase of evolution as regards the combustion of bituminous coal and the absorption of radiant heat.

In the larger modern boilers of the cross drum type, the amount of water is considerably less per unit area of heating surface. The rate of driving has also been increased. Consequently, the time required to empty the boiler by evaporation has been reduced in the ratio of, say, five to one, or even more.

Another interesting line of evolution is the tendency to surround more of the furnace with heat absorbing surfaces, including water walls, radiant superheaters and, in the case of pulverized fuel burning furnaces, with water screens over the ash pit. As a result, many boilers have been converted to a hybrid type intermediate between externally and internally fired boilers.

The most recent innovations, in connection with the application of pulverized fuel, involve what is practically the complete conver-

sion of the large water tube boiler to an internally fired type with the refractory walls either shaded by vertical water tubes or omitted altogether.

The application of pulverized fuel to large internally fired boilers has been made possible by the adaptation of the principle of turbulent combustion. Otherwise large refractory ignition chambers would be required. With two companies working along different lines on the application of turbulent combustion in boiler furnaces, it will be interesting to watch the results obtained in service.

As a matter of historical interest, we may add that a somewhat similar form of turbulent combustion has been in use for about ten years in small heating furnaces fired with pulverized coal in the drop forge shop of the American Locomotive Company in Schenectady. The combustion air is supplied by a high pressure fan and is fed into a refractory lined furnace thru two opposed tuyeres, allowing the blasts to impinge directly. The fuel is admitted thru one of the tuyeres. After the furnace has come up to temperature, the whole interior is filled with a uniform glow.

At the present time, pulverized fuel is well adapted to some types of service. The mechanical stoker, however, still holds its own place in several fields and has been improved under stress of competition from the rival method of burning coal.

High grade coals, of semibituminous rank, are burned efficiently on mechanical stokers. Each type of bituminous coal, however, is a separate problem and each plant is usually designed for burning a specific type of coal.

Most types of coal can be efficiently burned in pulverized form and in an emergency, a pulverized fuel burning plant may be fired with any available type of bituminous coal. In many parts of the country this is an advantage. Many low grade coals require larger grate-areas, when burned on stokers, than in the case of high grade coals. There is less difference in the furnace volumes required for combustion of different coals in pulverized form, and less difference in the efficiencies obtainable from high or low grade coals.

With the development of internally fired water-tube boilers, there should be a marked reduction in the cost of refractory maintenance. A boiler of this type will combine a minimum thermal

storage capacity in the furnace with the relatively small quantity of water characteristic of large modern boilers.

The adaptation of automatic combustion control will be simplified by the more rapid response of the furnace when called upon to change the rate of heat liberation in synchronism with the demand for steam.

Under present conditions, a pulverized coal fire is more responsive to control than a stoker fired furnace. At the same time it is more in need of automatic combustion control owing to the lack of stored energy in a fuel bed.

Similarly, furnace fires can be more economically banked with pulverized coal owing to the absence of stored thermal and chemical energy in a fuel bed. If the refractories are largely eliminated, no coal need be burned in internal furnaces. It should be sufficient to keep banked boilers hot by the condensation of steam from live boilers, or by the circulation of hot water.

A particularly advantageous application for internal firing should be possible in reheat boilers where the control of superheat requires rapid control in the heat supply, from the furnace, when the load drops suddenly. A few boilers of this type are now in operation on base load service and they have proved easier to control than had been expected, altho most of them are equipped with stokers. However, when reheat installations become more numerous it will not be possible to operate all of these units on base load. Facility of control will then be an important factor when operating on variable loads. Similar conditions may arise in the future in connection with possible developments in higher steam temperatures or in series boilers. It would seem logical to expect that new developments in these fields may be more readily made with internal firing.

DISCUSSION

F. R. Low.* (Read by C. H. BERRY, Associate Editor of *Power.)*

It is fitting that one of the sessions of a conference on bituminous coal should be devoted to the consideration of the use of coal for power development for it is safe to say that fully one-half of the coal mined is used for this purpose. Any plan for the wise conservation of this dwindling resource must take into account the problems of the

*Editor of Power.

power plant and must mold its developments in conformity with the needs of the boiler room operating engineer.

But the power plant presents more than a problem. It presents a splendid opportunity for the saving of coal. The average efficiency of boiler rooms, large and small, is probably below 60%. That indicated by tests of 400 industrial establishments by David Brownlie of England was 56% and, curiously, that for 77 establishments tested by the Fuel Engineering Co., of New York was the same figure. A sustained efficiency of 70 to 75% is entirely practicable with ordinary apparatus operated by ordinary attendants and with ordinary conditions as to load factor and variation of demand. Efficiencies of 75 to 85% are maintained month in and month out by some of the large public utility stations and industrial plants.

An increase of average efficiency from 60 to 75% would save one-fifth of the coal used under boilers. One-fifth of one-half is one-tenth of the coal mined—some 60 million tons annually.

Do not translate this into dollars simply. Look at the labor that it would release in its mining and transportation, the reduction in cars and locomotives, and yardage in storing and handling at the point of consumption, to say nothing of the diminished depletion of an asset for which we are finding multiplied uses as its exhaustability begins to become apparent.

It is within only a comparatively few years that coal has been extensively used for the production of power, and the first large use of the "fire engine" was pumping out the mines from which the coal was being won for other than power purposes. Our whole steam-driven industrial, railroad and steamship systems are hardly a century old. And yet in that time we have become so dependent upon power, produced for the most part by the burning of fuel, that it is as vital to the modern social organization as are food and water to the animal organism.

We depend upon coal for warmth and light and cooking in our homes, for heating and processing and power in our industries, while out of its grimy mass come, at the touch of the chemist's wand, gaseous and liquid fuels, fertilizers, perfumes and dyes that reproduce the fragrance and beauty of the sun-painted blossom, and wonderful unsuspected substances that alleviate human suffering and perform feats of chemistry and photography.

It will take but a few centuries to make serious inroads upon this legacy of the ages at the swiftly increasing rate at which we are drawing upon it. In the 50 years between 1869 and 1919 the power employed in the manufacturing industries of this country increased from less than a million and a quarter to over twenty million horsepower. Last year, the electric public utilities of this country alone, a development entirely within the memory of many who are attending this conference, turned out 61 billion kw. hrs., and twice that is the

probable power output of the electric light and power companies of the world. The tremendous development of the past quarter century in the use of the internal combustion engine for automotive purposes has established conditions and needs that are likely to outlive the natural supply of liquid fuel and turn to coal for their fulfillment. All of these demands, increasing from year to year in kind and number and accelerating in magnitude are hastening us toward that day when the surviving inhabitants of this fast cooling planet will be warring with each other for the few heat units that it still contains.

The limitations of the process by which power is produced from fuel by generating high molecular velocities through the attraction of the fuel for oxygen and then recovering this kinetic energy by slowing the molecules down, (i. e., reducing the temperature of their composite substance) involves discarding the larger part of this molecular motion which is still in the medium at ordinary temperatures. The molecular energy in steam could be converted entirely into power only by expanding the steam to the absolute zero of temperature, and the heat remaining at 200-odd degrees Fahr. is a large proportion of the total. Condensation of the steam and the reduction of the condensate to the original temperature by abstracting the heat through some process in which it is usefully applied offers a means of getting a return of 100% instead of 20% or less upon the heat invested.

Recent developments in the use of high pressure in the steam turbine have enormously increased the possibilities of this dual use of steam, i. e., the generation of power by dropping steam from a high level of pressure and temperature and exhausting it at temperatures and pressures adapted for heating and industrial purposes. The use of initial pressures and temperatures that a few years ago would have been considered impracticable makes it possible to generate large amounts of power from the steam before it is sent to the processes and the turbine may be bled at any pressure stage for steam uncontaminated by lubricant as it was in the displacement engine. There must be synchronism of demands for power and heat, but where use exists for heat at moderate temperatures there is an opportunity for the concurrent generation of power at the least cost and highest thermal efficiency of any of the processes known to man.

The realization of this ideal involves the location of the power plant where such uses for its exhaust may exist or can be created. The justification for the continued operation of many industrial plants is found in the use within the establishment, of heat from its exhaust steam for the generation of which fuel would otherwise have to be specially burned. Some of the public utilities have found it profitable to market their exhaust, or to combine with refrigerating and chemical plants that can time their processes to the supply.

Another idea, discussed by Mr. Orrok in one of the papers to which we have just listened, is to locate the power generating station at the

mouth of mine and convert the coal on the spot into the easily transmitted electric current. This is one of the features of the Giant Power Project proposed for Pennsylvania, the mine mouth plants to be of 300,000 kw. installed capacity and upward.

At 50% load factor and two pounds of coal per kilowatt hour such a station would use 3,600 tons of coal per day. If, as is also proposed, the coal is subjected to low-temperature carbonization before use in order to save the by-products it would take some 4,800 or 5,000 tons per day to run it. There would probably be considerable economies in fitting up a mine for this continuous mass production but so long as those who must be depended upon for its operation maintain the right to work it or shut it down at their pleasure or at the command of a group organizer, there may be some hesitation about making the portion of the public served by such a station so entirely helpless under such a menace.

The costs and advantages of carrying the coal to the water or the water to the mine are capable of engineering definition and comparison. We need more definite information with regard to the costs and performances of spray ponds and cooling towers. A 300,000 kw. station with 50% load factor would require some 300 to 400 millions of gallons of water per day, a supply sufficient for a city the size of Chicago. When, as is frequently the case, the water supply is near the load center the combined advantages of cheap vacuum and short transmission will for the usual case, justify the current practice.

In determining the relative advantages of these different locations and possible combinations of services, each case must be studied from the point of view of its commercial or market situation as well as its engineering possibilities. The new station of the Columbia Power Co., at Cincinnati, is said to have run a full month at the rate of 12,500 B.t.u. per kw. hr. Many of the better stations are putting current on the switchboard at less than half a cent per kilowatt-hour operating cost. No station can, through location, combination of service or natural advantage, reduce this figure enough to satisfy the anticipations that have been aroused in the mind of the lay consumer as to the possible reduction in his light or power bill through improved conditions of production.

The first talking machine was a crude reproduction of the animal mechanism. The first automobile was simply a horseless carriage. The first boiler was nothing but a glorified tea kettle. Just as the modern reproducer of human speech differs from Barnum's bellows-operated imitation of a human throat, just as the modern touring car or truck differs from the self-propelled buggies of the early automotorists, so the apparatus for producing steam has lost any resemblance to the early forms, and in pressures carried in capacity in a single structure and per unit of heating surface and of volume, and for sustained efficiency under express service, has revolutionized boiler-room practices.

The latest development in this direction is that described by Mr. Kreisinger and the profession is watching with interest for reports of its performances under service conditions.

Perhaps the widest indicated departure from present practice lies in the direction of distillation or carbonization of the coal with winning of by-products which are of more than raw fuel value and the improvement of the residue as a solid or pulvurent fuel.

Pulverization presents for carbonization some of the advantages, such as vastly magnified surface exposure and accelerated action, that it does not for combustion and two of the papers at this conference deal with the possibilities arising from pulverizing before carbonization. We have in these two papers, that of Dr. Runge on "The McEwen-Runge System for the Low Temperature Distillation of Coal," and that of Mr. Trent, just presented, examples of what are analagous in this operation to the open and closed heater or the jet and the surface condenser in the steam plant. In the McEwen-Runge process the gases from the source of heat are in contact with the coal and mingle with the products of its distillation. In the Trent process they are separated by a metallic wall. In the first the coal is showered through the heated gases, in the latter it flows like a fluid stream over surfaces kept hot by gases upon the other side. I wonder if either of these processes contemplates the possibility of keeping the hot pulverized coke moving along to immediate use in the boiler furnace. In such a case the necessity for synchronism of process with power demand seems evident.

This is a problem of growing importance. It is not now a pressing matter with the power plant engineer, but is one of the things he is beginning to view in his long look ahead. As the fuel and chemical raw material markets change, as they are bound to change, this problem is one which much must be attacked jointly by the power engineer and the chemist for the ultimate welfare of the race.

W. TRINKS.* May I make a suggestion to Mr. Trent? In the final publication of the transactions, the cost of pulverizing a ton of material should be included if it is at all possible, and I think it would be appreciated, to have the power consumption in the proceedings.

WALTER E. TRENT. We have some tests under way, and if it is at all possible we will have these data as soon as the publication. If not, it will be published as soon after as we can get it, ourselves.

J. C. HOBBS.† Mr. Orrok has very clearly analyzed the subject of Mine Mouth Power Plants. It would be a good thing for the country if many business men and public officials were disillusioned concerning their impression that coal alone is needed to procure power. May I briefly emphasize the necessity of having available a large quantity of a good quality of water also?

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Approximately ten pounds of steam is evaporated by each pound of good coal. Water for this purpose can be distilled and used over and over again with from 2% to 5% "make up" added to each cycle so that in a very modern plant this is not a great factor.

But condensing water is the determining factor. About 50 pounds of water is required to condense each pound of steam. It is therefore 500 times the weight of coal burned.

Many modern stations are each pumping a million tons per day through their condensers. This is equivalent to the average flow of a large stream. The acid water usually found near mines due to mine waste contains sulphuric acid. It eats the condenser tubes rapidly so that increased tube maintenance together with the transmission costs, so well shown by Mr. Orrok, must be deducted from the savings in freight on coal. To get a visual conception, imagine a diagram with three bars, one—the width of a pencil line—representing coal, one, a tenth of an inch wide, representing the steam, and another five inches wide for condensing water.

"Penny wise, pound foolish" is the one who considers coal only in connection with a steam power station.

Has Mr. Trent considered the effect on the mobility of coal of pipe line radiation with the resulting decrease in temperature? A decrease usually means less volume, a decrease in velocity, a separation of coal from the carrying gas, and ultimately a plugged transportation line. Plugging occurs frequently enough when the velocities are increased near the delivery end due to a decrease in air pressure.

Condensation would also be expected without air to absorb the moisture condensed by the relatively cold pipe walls. If it were practical to increase the coal temperature indefinitely, a sufficient volume of gas could be evolved to maintain the velocities even at the discharge end, but it must be remembered that coal becomes sticky at relatively low temperatures.

This action limits the temperature of the primary air used to feed coal into boiler furnaces. It would be appreciated if Mr. Trent would cite the outstanding facts concerning length of line, temperature of coal, etc., on a typical installation in which the coal is conveyed by its own gas. A description of the method of heating the coal would also be of interest.

With reference to the explosion hazard it would appear that a mixture of coal and gas introduced into a pipe containing air would constitute a greater hazard at the beginning and end of each transportation process, than coal only. This would be increased by the arrangement of delivering direct to the furnace. "Burning back," as with gas only, would be expected.

Dr. Kreisinger has presented a very interesting paper on the effect of turbulence and water cooling. I believe I agree with him thoroughly

on the matter of water cooling. Five years ago there were no large water cooled furnaces. Five years ago the brick manufacturers were straining their resources to obtain a brick that would stand up so that we could obtain the full value of pulverized coal, and not have to burn it inefficiently because the furnaces would not stand up. Today we have the large water cooled furnaces and in fact there are few large furnaces being constructed, that I know of, that are not water cooled. Today the manufacturers of refractories for boilers have no problem to solve in connection with new installations.

A statement was made yesterday that I think should not go unchallenged. I have been unable to get in touch with its author, Mr. Samuel Taylor, but you saw on the screen today a picture of a large pulverized coal plant to be operated in the city of New York. The statement referred to is the one in which Mr. Taylor implied that the laundry companies are reaping a great harvest due to the pulverized coal ash. I have made many investigations, and I have not been able to find a single serious condition due to ash from pulverized coal furnaces. It is true that part of the ash is discharged through the stack but ash cinders and tarry smoke were discharged by stokers, the best previously known method of burning coal. That dirt was what might be called a dirty dirt, whereas pulverized coal ash is light in color and is free from the sticky, staining quality of the darker stack discharges from stokers.

Along with the progress toward higher efficiency, engineers are also making strides toward gas cleaning. Both electrical and water cleaning have been used.

Another fact which should be considered before broadcasting any scare is the increased efficiency and the decrease in quantity of coal burned. Less coal tends toward less ash.

It would seem that Mr. Taylor would do well to reconsider his statements and in justice to all concerned modify them so as to give credit where credit is due rather than censure those responsible for progress and advancement.

W. W. PETTIBONE.* Dr. Kreisinger brought out the fact that with water-cooled furnaces B.t.u. rates of twenty to forty thousand per cubic foot of combustion space per hour have been reached and maintained. I would like to inquire what the minimum B.t.u. release is in water-cooled furnaces of that type—what the minimum is which will still maintain combustion in a completely water-cooled furnace. My conclusion is that water-cooled refractory lined furnaces are to be recommended, rather than completely water-cooled furnaces, due to the fact that a completely water-cooled furnace must be maintained at a very high rating, continuously. Any attempt to operate that unit at a lower or low rating, which is necessitated by the load conditions, brings on

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incomplete combustion in the furnace, due to the great tendency of the water-cooled surface to reduce the temperature in the furnace to the point where combustion is not completed.

HENRY KREISINGER. I shall answer Mr. Pettibone's question as far as I can. The rate of heat absorption by the water cooling surface in the furnace varies with the rate of heat generation. If the rate of heat generation is lowered the rate of heat absorption is lowered at a greater rate. This lower rate of heat absorption is mainly due to the fact that at the lower rates of heat generation the surface of the flame which radiates the heat is much smaller than it is at the higher rates of heat generation. Thus, at high rates of generation the flames may fill the combustion space of the furnace completely and the surface of the flame is very large. At lower rates of heat generation the flames fill only part of the furnace and the surface of the flame is smaller. Although at the low rates of heat generation the surface of the flame may be at the same temperature as it is at the high rates, less heat is radiated from this surface because the surface is smaller. It must be born in mind that the amount of heat absorbed by the water-cooled furnace surface is proportioned to the surface of the flame and not to the cooling surface of the furnace. For example, the amount of heat radiated from a candle burning in a large hall is proportional to the surface of the candle flame and not to the combined surface of the walls, ceiling and floor of the hall which absorb the heat. Although the candle flame may radiate heat at the rate of 40,000 B.t.u. per square foot of the surface of the flame, the walls of the hall may absorb heat at the rate of less than 1 B.t.u. per square foot of surface per hour.

From my observation during tests of water-cooled furnaces, I can say that the rate of heat generation as low as 10,000 B.t.u. per cubic foot of total combustion space can be obtained without any difficulty from incomplete combustion due to too low furnace temperatures, and I think that with proper burners, even lower rate of heat generation could be obtained. At these low rates of heat generation only part of the furnace is filled with flame and the rate of heat generation is really about 20,000 B.t.u. figured from the furnace volume that is actually used. The remaining volume of the furnace is free from flame and therefore does not take any part in the combustion. Refering again to the burning candle in the large hall, the actual rate of heat generation figured on the actual volume filled by the candle flame is probably 20,000 B.t.u. per cubic foot per hour, whereas if figured on the total volume of the hall it may not figure more than 1 B.t.u. per cubic foot per hour.

My paper deals with water and steam cooled furnaces in general without much reference to the details of such surfaces. The names of the makers of these surfaces were purposely left out. In the first

furnace described in my paper, three walls of the furnace are made of so-called radiant superheaters and reheaters. The fourth wall is of water-cooled surface of special construction. The roof of the furnace is formed largely of the boiler. Three makers of metallic-cooled furnace walls are represented in that particular furnace.

The first consideration in a water-cooled or steam furnace is to make the walls durable in order that full advantage can be taken of turbulent mixing without destruction to the walls or to the accumulation of fused slag which would be difficult to remove from the furnace. In addition to the durability of water and steam-cooled furnace walls, there is a desirability to make these walls useful by letting them absorb heat. There is no doubt that water-cooled furnace walls cost more than refractory walls. The extra cost can be justified easier if such furnace walls can serve also as part of the boiler by permitting them to absorb as much heat as possible from the flame and thus relieve the boiler of some of its work and make the boiler itself smaller.

To cover the water-cooled furnace walls with refractory would be to defeat this additional advantage. Why should we spend more money for water-cooled surfaces and then cover them with refractories to prevent them from absorbing heat. Let us give them a chance to be useful to the fullest extent. If there is the proper amount of air and good mixing there should be no difficulty in obtaining complete combustion. The average rate of heat generation of 10,000 to 40,000 B.t.u. per cubic foot of total combustion space gives us a working range from one to four, which should be wide enough working range to satisfy any ambitious engineer.

Chairman E. M. Herr.* Mr. Trent, will you answer the question raised by Mr. Hobbs relating to the loss of temperature by radiation?

Walter E. Trent. Moving pulverized coal is a good deal like moving steam. If the pipe is not insulated you will get some condensation. It must be borne in mind that in this liquid-like condition it is moved as a liquid at a high rate of velocity. It is not dangerous in the pipe. As to the danger of vapors like coal gas issuing from a point, it certainly is not dangerous as long as it is in the pipe, no more than gasoline or oil or natural gas or artificial gas. When taken out of that pipe it should be at a furnace or point of combustion where combustion is required.

J. C. Hobbs. Mr. Trent speaks of pushing coal through pipes at high velocity. This coal has to be pumped in, sometimes. I cannot conceive of that being maintained absolutely air tight unless under some new kind of process.

Walter E. Trent. My conception of it is that it is going direct to the point of consumption, the same as gasoline. I have not in mind discharging of vapors en route.

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J. C. HOBBS. Then in that case your feeders actually would be located at the point of preparation. You would have to maintain separate lines and feeders for each of the furnaces.

WALTER E. TRENT. That is primarily what we have in mind.

J. C. HOBBS. You would then have a multiplicity of long lines.

WALTER E. TRENT. I would consider that one of the advantages of it.

J. C. HOBBS. There are many things which would make such an arrangement impractical in connection with an efficient central pulverized coal system. First, the control apparatus would be located at a great distance from the furnace. Second, coal does not flow out of a discharge line at the same instantaneous rate at which it is fed because of accumulations and wave-like pulsations which result in a very uneven flow and the possibility of the fire going out between there and the furnace becoming filled with fuel. Third, the full length of each line must be kept in service continuously as long as the furnace is in use. Leaks in the transport line would require an interruption in service to be repaired.

WALTER E. TRENT. I believe when things are started on their way they should be kept going. Your point is well taken, however, because coal loses its mobility when it condenses. It is analagous to a steam line.

J. C. HOBBS. What is the temperature at which coal becomes mobile enough to start?

WALTER E. TRENT. That would depend entirely on the coal used, usually a starting point somewhere above 150°C.

J. C. HOBBS. Dr Kreisinger asked the question, "What is the use of covering up heating surfaces?" He also made a remark to which I must take exception; i. e., that flame impingement can be allowed on water-cooled surfaces. I do not agree with that because actual experience has proven that flame impingement cannot be allowed to continue very long, or at very high velocities on bare side wall tubes without distress and tube failures. The idea of covering up is more to cover the desire of unreasonable engineers for a wider range of rating and also to protect heating surface which is a part of the furnace. I don't quite agree with him on these points.

HENRY KREISINGER. Mr. Hobbs is one of those men whom I had in mind when I said that a working range from one to four should be enough to satisfy any ambitious engineer. About three years ago he was in charge of the installation of a heating plant consisting of steam generating units of about 30,000 square feet of heating surface. He demanded a working range about 30 to 300% of the rated capacity of the boiler. The three walls, the bottom and the roof of the furnace were water-cooled surfaces. The front wall was made of refractory. The furnaces operated well between about 80 to 300% rating. With somewhat more elaborate air adjustment, Mr. Hobbs was able to re-

duce his rating to about 30% with more or less satisfactory operation.

As to his remark of covering some of the water-cooled furnace surfaces with refractory in order to protect them from becoming overheated, it is questionable whether such covering is necessary. The water-cooled walls under severe conditions do not absorb more than about 70,000 B.t.u. per square foot of surface. Under the same conditions the first two rows of boiler tubes absorb the heat at the rate of about 120,000 B.t.u. per square foot of heating surface. Why is it not necessary to cover the first two rows of tubes of the boiler to protect them against excessive heat if the furnace walls which absorb heat at much lower rate are to be covered with refractories?

J. C. HOBBS. The conditions on the boiler tubes are much more favorable than on the side walls.

HENRY KREISINGER. That is a question of opinion or perhaps point of view. Mr. Hobbs may look at this refractory covering from a different point of view, so that we may not be so very far apart in our argument. I shall tell a story illustrating two different points of view on the same thing. It is getting late and the audience may be tired of listening to technical discussions and an untechnical story may act as a refreshment.

Last night I came to the dinner given in honor of the Foreign Delegates. I was asking some gentleman where my seat was, and he showed me a paper giving the plan of the dining room and pointed to my name apparently at table nine. I went to table nine and found Mr. Hobbs occupying my seat, as I thought. I said, "Mr. Hobbs, you have my seat, my table is number nine." He said, "Well, I will see about that," and went to get a plan of the dining room to find what table I belonged to. Coming back, he poined to my name on the paper and said, "Here you are, table eleven, that is where you belong." I said, "No, that looks like table nine to me."

The fact was that the number happened to be a Roman numeral. Mr. Hobbs looked at it from one side and saw XI, the I being after the X, but I, looking at it from the opposite side saw the I before the X and saw it as number IX. The same thing from different sides appeared different to the two of us.

J. C. HOBBS. Table number eleven turned out to be the Doctor's table as was clearly shown when the sheet was examined right side up. The fact that boiler tubes do not fail as quickly as tubes in the side walls indicates that it does make a difference which side is up and that protection for side wall tubes is desirable.

W. W. PETTIBONE. I am willing to stand corrected that the National Electric Light Association had it as their opinion that the refractory covered furnace walls had proven to give better results.

MORGAN B. SMITH.* The statement was made that the manufac-

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turers of boiler refractories no longer have a problem. I do not believe that should be allowed to stand as quite so bald a statement. I am with a corporation which has some forty-odd boiler plants. We do not operate over 170 lbs. per square inch pressure and probably not over 165. As we figure it, it would be very difficult to justify the installation of the water-cooled system, especially a very complicated system, and I may go so far as to say that the sale of a water-cooled system at one of our plants was totally killed on account of the high first cost.

FRANK M. GENTRY.* We have listened with a great deal of pleasure to Mr. Orrok's interesting discussion of mouth of mine power stations. This is a subject of widespread interest and one which deserves full consideration because of the commonly misunderstood facts in the case. Mr. Orrok has admirably pointed out that there is far more underlying the selection of a suitable and economical site for a steam power plant than mere proximity to the coal fields.

A study of sixteen power plants located upwards to 40 miles distant from the mine tipple showed that all obtained their condensing water from rivers except three, two of which used artificial lakes and one a spray pond. None used cooling towers. The largest installation of the three exceptions was only 70,000 K. W. One small installation obtained its boiler make-up from artesian wells and one obtained it from the city water supply while practically all the rest used distilled river water. Five out of seven of these plants reported lack of condensing water as the factor limiting expansion, one reported lack of load and one reported uneconomical distribution.

We all know that pumping large quantities of water is a costly proposition, but, nevertheless, a plant with an initial installation of 80,000 K. W. has recently been built in the Rand region of South Africa in the center of the coal fields where the condensing and boiler make-up must be pumped six miles from the Oliphants River. The boilers are designed to burn refuse coal ordinarily dumped at the pit head. The power will be transmitted at 132,000 volts 65 miles to Brakpan while an extension will carry it 90 miles to Johannesburg.

It seems to me that from the standpoint of reliability, which is the all potent factor in power plant operation, a point ordinarily overlooked is that the steam power reserve available for drought periods will be lessened if the mouth of mine plant is threatened by condensing water shortage during the dry season when the interconnected water power is suffering from the same drought. In other words, at the very time the steam reserve is needed on account of low water in the hydro-electric reservoirs, the efficiency of the steam station will be at its worst, first because of lack of water due to the drought, and second

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because the dry periods occur when the seasonal temperature is near its highest.

In districts where there is a cheap coal supply and where freight is a high proportion of the fuel cost at the load center, it may be economical to locate a steam power plant at the mine mouth and operate it non-condensing, but still such a procedure would require an enormous amount of boiler make-up which in districts remote from ample water supply would be difficult to secure. In particular, non-condensing plants at very high pressure of 1500 lbs. per sq. in. or more may prove very economical if located convenient to chemical industries where the exhaust steam can be used in large quantities. But such favorable sites are almost as scarce as the proverbial hen teeth.

In 1921 Henry Flood, Jr., in connection with the report on "Superpower for the Region between Boston and Washington," compiled by W. S. Murray and others, investigated possible sites for mouth of mine plants on the eastern slope of the Allegheny Mountains in Pennsylvania and Maryland. Because of low flow and pollution all creeks and rivers in the anthracite region were eliminated except the Susquehanna. On this river only three sites were found suitable for stations of 300,000 K. W. which was deemed the minimum size for economical transmission to the load centers. These sites were at Pittston with an average haul of five miles from the northern coal field, at Nescopeck with an average haul of 15 miles from the middle coal field and at Sunbury at the southwestern extremity of the western coal field within an average haul of 25 miles, so that literally speaking none of these was actually at the mine mouth. Within a maximum distance of 175 miles of these three sites are located the New York, Philadelphia and Baltimore load centers which have an estimated increase of 3,550,000,000 K. W. H. from 1922 to 1930. These 300,000 K. W. stations if located at the sites mentioned and operated at 50% load factor would have an output of 3,940,000,000 K. W. H. or only slightly more than enough to provide the estimated increase to 1930 for these three cities. In the bituminous coal fields along the eastern slope of the Allegheny Mountains only one site suitable for as much as 180,000 K. W. was found at Cumberland where the average haul was 35 miles.

To sum up the question of mouth of mine power plants, I feel that in a problem such as this, no generalities can be drawn and that no general scheme of interconnection based upon mouth of mine superpower plants can be outlined because, as Mr. Orrok has ably pointed out, each case demands separate consideration.

A. BEMENT.* The interest in the combustion of coal in powder form, and installation of equipment for that purpose, has probably shown greater and more rapid development than any other method of burning coal. In fact, powdered coal combustion is the prevailing fash-

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ion. The process has certain economic possibilities; the most important one should be the ability to use cheap fuel. There is a large production of coal through 3/8" or 1/4" round hole screen. The 3/8" size sells at 30¢ to 40¢ per ton below the cost of 1 1/4" or 2" screenings. Thus far the principal market for this material has been to plants manufacturing cement, at which it is further pulverized and burned as powder in the process of clinker production. This fine coal has been used for many years in the cement industry with entire satisfaction, and was naturally looked upon as a most acceptable material for use in power plants burning powdered coal. Its use thus far, however, has not been entirely successful, due to difficulty in handling when wet; in other words, when carrying surface moisture. While this fine coal when dry gives no trouble it is liable to arrive wet at times due to weather or other conditions, and these occasions of wet condition have made it often impracticable to use it, with the result that 1 1/4", 2" screenings, or large preparation is used. The trouble with the fine coal is caused by its sticking in conveyors or driers on its way to the pulverizing mill; to minimize this tendency the larger preparation is used.

The reason that this fine coal for use in steam production has failed to meet with the same success as it has in the cement industry, is a matter of difference in equipment provided for handling the coal, and it would appear that the makers of powder burning equipment must so improve their appliance so as to enable the use of this fine material if they and their customers are to realize the advantages of cheap fuel. One may seriously question the advisability of installing powder instead of stokers, if the powder plant must use the same or better preparation than it required for the stoker.

BITUMINOUS COAL AS A SOURCE OF CHEMICAL PRODUCTS

By Jean Bing

Director, Technical Service, Coal Tar Producers and Distillers Association, Paris, France.

We shall consider this subject from an economic point of view; many authors, more qualified than we are, treat it from the technical one. The economic point of view is, however, very important and is too often disregarded by technical men, although value and interest play an important part in the life. It is, in addition, always necessary to consider what may be the possible utilization of a product one intends to make. It is also necessary to find how to utilize by-products of such an operation.

In this lecture we intend to show how coal may be utilized as a source of chemical products, and which problems of utilization of by-products have to be faced. We shall give statistical data relative to the main products obtained and point out possibilities of further developments.

Coal—and by this word bituminous coal will be considered more especially—is known as a fuel, but it is also the industrial source of most of the chemical products of organic chemistry; even of inorganic. Several rocks may be considered as excellent road material, but would never be used in such a way if they should contain mineral ores. A similar position may be taken for coal.

Let us then consider coal as a chemical ore. This ore may have to be dressed,—and it is generally a necessity in Europe but more particularly in France. In the States the seams are very regular and coal may generally be sold at the mouth of the pit without any special dressing. We have, however, in Europe not only to screen it but also to wash it and even to float it so as to diminish the ratio of ash, which would be transported and treated. (See Dr. Lessing's paper.) Cost of preliminary treatment will generally be smaller than additional expenses due to transportation and treatment of inerts.

Coal being properly dressed may be treated chemically. Prac-

tically three different ways have to be considered as industrial:—oxydation, distillation and hydrogenation.

Oxidation

Oxydation of coal takes place in producers, either blown with air or with oxygen. We produce in this way carbon monoxide, which may be burned. This treatment is really not a chemical treatment but a means of transforming solid fuel into a gaseous one. Chemical products contained in coal are not recovered.

Distillation

The distillation process of treatment is by far the most important now and has been used more than one hundred years. We have to consider high temperature distillation and low temperature processes.

Two industries are involved with high temperature distillation, viz., gas industry and coke industry. The technique of both is very similar but several differences occur between them, chiefly in Europe.

The gas industry has as its main object to produce, starting from a ton of suitable coal, a maximum volume of gas to be sold for lighting, heating or power purposes. This industry was created in Netherlands by Minkelers (1783), in England by Murdoch, and in France by Lebon (1792). Those inventors worked independently, the one from the other.

The coke industry has as its object to provide metallurgical works with a reducing agent purer than crude coal. The first idea of distilling suitable coal for that purpose seems to have been had in, or about, 1750 by foundry men of Newcastle, and by the Prince of Nassau-Saarebuck at Sulzbach on the Sarre.

Both industries take as raw material suitable bituminous coal and distill it. A ton of coal gives in that way approximately 300 m. c. (1100 cu. feet) of gas, 650 kg. of coke, and about 50 kg. of tar. But distillation requires heat, and there will be a first difference between the two industries: A gas man wishes to have a maximum of gas; he will then burn part of the coke obtained,—let us say, 150 kg.—to heat the coal to be distilled. A coke merchant, on the other hand, will heat his coke ovens with part of the gas obtained —let us say, 160 m. c. Hence, a ton of coal gives, if treated in gas

works, 300 m.c. of gas, (1100 cubic feet) and 500 kg. of coke. If treated in a coke oven plant, 140 m.c. of gas, (500 cubic feet) and 650 kg. of metallurgical coke.

A second difference lies in the judicial and economic position of these two industries. Distribution of gas is a public utility and has to be under some government control. Coke production is a mere commercial operation.

A third difference lies in the importance of the works. In a small town the gas works may be a very small plant. Cost will be higher than in a larger plant as relative importance of labor in the output will be more important. It would be inadvisable for those causes to erect a coke oven plant of small importance. We must say that this third difference existed chiefly years ago. Now gas may be distributed as far as 100 miles and small gas plants would not be constructed any more. We should erect one large plant common to several towns. This was done in Alsace in 1910, and has been largely extended since that date. In France, for instance, we may quote many examples: Suppression of small gas works in the suburbs of Lyons and of Lille. More recently, as we had to rebuild destroyed gas works, we decided not to erect those of Chauny, Tergnier and Noyon, but to furnish these localities with gas coming from St. Quentin, thirty miles away.

It is possible in certain cases to combine the two industries. For instance, in areas where there are many coke ovens. We must remember that in case of a metallurgical crisis the owners of coke ovens may discontinue their production. The distributor of gas is not entitled to such license, as he runs a public service. It is then possible to rely on coke ovens only if there exists such a number of ovens that a minimum will always be active, in the event of a metallurgical crisis, so as to meet the consumption of gas. These conditions are generally found in the most important coal fields, like Ruhr, Sarre, Belgium, North of France, Loire, &c. We find the same situation in Pittsburgh, Harrisburg, &c. This may also be the case in metallurgical centers provided with their own coke ovens, as in Lorraine or at Detroit, Baltimore, &c.

It is even possible to consolidate to a further extent those two industries on a larger scale. If we design coke ovens for a maximum production of coke with a corresponding production of gas far in excess of the consumption, we shall heat the plant with the town

gas in excess. In case of a metallurgical crisis, part of the ovens will be put out of service. If it becomes necessary at a certain moment to increase the production of town gas, it is possible to heat the plant no more with that town gas but with producer gas. If the metallurgical crisis becomes more severe, more ovens will be put out of service and part of the coke will be treated in a producer to make water gas, which will be mixed with ordinary town gas so as to meet the demand.

This system is used on a large scale in the States, but not in France, as a maximum of 15% of carbon monoxide and a minimum heating value are allowed in distributed gas. It seems interesting to give information relating to both industries.

Gas production depends upon consumption per head of inhabitant, and varies then according to the population and to the individual consumption. Population is a local factor; but we may have an action on individual consumption, i. e., efficient advertising. Industrial uses of gas increase individual consumption. A good example may be given from England:—Birmingham, where town gas is used for metallurgical purposes, like reheating, annealing, &c. Climate also plays an important part. In Italy, for instance, where the climate is mild, gas is less used for heating than in England. Certain habits have also an influence. Consumption of gas in bath heating devices is quite important. Baths are frequent in England, not very frequent in France and scarce in Italy. Then we shall not be surprised to find for those three countries, the population of which is quite similar (40 millions), figures of gas production for 1925 as different as:

	Millions of m.c.
Italy	386
France	1485
United Kingdom over	3,000

It would then be obvious to give statistical data concerning the gas industry. Let us remember that production increases from 5% to 10% per year, according to the efficiency of advertising.

(Figures relating to English gas industry, which is the most prominent in Europe, will be found in Dr. Gill's paper).

Coke industry is, on the other hand, a mirror of the development of metallurgical industry.

In the United States, a peculiarity in the coke industry is that part of the plants are beehive plants. By-product plants are gaining in importance chiefly since 1915, where calls for by-products become tremendous. Now beehive plants seem to be chiefly flywheels in the production.

Year	Output (Millions of tons) From Beehive Plant	From by-products	Total	Percentage Beehive	Percentage By-product
1913	33.6	12.7	96.3	72.5	27.5
1915	27.5	19.1	91.6	66.2	33.8
1917	33.2	22.4	55.6	59.6	40.4
1918	30.5	26.0	56.5	54.0	46.0
1920	20.5	30.8	51.3	40.0	60.0
1921	5.6	19.7	25.3	21.9	78.1
1922	8.6	28.6	37.2	23.1	76.9
1923	18.0	37.6	55.6	32.3	67.7
1925	10.7	40.0	50.7	21.1	78.9

We observe the results of a metallurgical crisis like that of 1921, when many coke ovens became idle—chiefly beehive ones. The United States is neither importing nor exporting coke.

Germany—All plants are now by-product ones:

Year	Total in millions of tons	Ruhr alone	Upper Upper Silesia
1913	34.6		
1919	31.7	25.2	1.2
1921	26.9	23.1	1.2
1925	26.8	22.5	1.1

In 1915 Germany exported 7.7 millions of tons, 4.4 of which went to France.

United Kingdom—As in the States, part of coke ovens are beehive ones.

Year	Total distilled millions of tons	Coke made	Percentage of by-product oven
1913	10.2		
1920	18.9	12.6	58
1921	6.9	4.6	62.5
1922	13.2	9	71
1923	19.8	13.4	71.7
1924	18.9	12.8	75.0
1925	6.3	?	?

Production is greatly affected by the metallurgical crisis. Normally England exports from 1.5 to 3 million tons a year, mostly to France.

France—The output in France is increasing rapidly as new plants have been started in Northern Coalfield Area and in Lorraine. Production of France in 1924 was on the same level as in 1913. In 1925 production reached 4½ millions of tons, but could not meet home consumption. Imports amounted to 5 million tons (Germany 4.4, Belgium 0.5) It must be remembered that France possesses by far the most important iron ore mines in Europe. France may then develop the coke industry. Belgium's output is similar to that of France, but Belgium is an exporting country (0.5 million tons to France).

BY-PRODUCTS COMMON TO BOTH INDUSTRIES

Three different kinds of by-products are recovered in gas works as well as in by-product coke ovens, viz., tar, benzol, ammonia.

Tar

Tar amounts to an average of 50 kilograms per ton of coal distilled. Figures vary according to the quality of coal used and to the process of distillation—higher in small retorts, it becomes lower in large coke ovens. Tar is by its distillation the source of most of the organic chemicals—dyestuffs, synthetic drugs, blast explosives, synthetic resin (bakelite), etc. It may also be burned or utilized on the roads either as a superficial protecting sheet or as a binding agent for other materials. It must be then observed that part of the tar constituents are unfit for that purpose and have to be removed by a partial distillation. For economic causes (distance between distilleries and producing plants) this is not a compulsory rule in France, but in other European countries the spreading of crude tar is forbidden.

Burning of tar does not occur largely in Europe, as there exists a lack of material there.

Distillation of tar gives these products:

Water up to 5% (¼% maximum of ammonia may be recovered)
Crude light oils.....from 1 to 2½%
Oils .....from 25 to 30 %
Pitch .....from 55 to 60 %

Ammonia will be treated with ammonia recovered from the products of coal distillation, also light oils. Tar oils may be treated so as to separate phenol oils, naphthalene oils, anthracene oils—for further treatment giving phenols, naphthalene, anthracene, etc. Oils are also

utilized as creosote for preservation of wood, and as fuel in Diesel motors or in special burners. Pitch is used for making patented fuel, which requires in weight 8% to 9% of pitch.

United States—Production of tar amounts to more than 2,000,000 tons (1922, 1920, 1923, 1910, 1924, 1925).

This country is the only one having a production exceeding calls for distillation. The quantity of tar distilled each year varies from 595 million tons (1921) to 617 (1922)—910 (1923)—? (1924)—? (1925) surplus is burned: 505 (1921)—803 (1922)—1,000 (1923). So we can say that 50% is distilled, 50% is burned. It is curious, however, to note a tremendous lack of creosote. Part of it could be recovered by distillation of that burned tar, but in such hypothesis U. S. would have an excess of pitch which could not find a proper market.

Germany—Production amounted to 1,600,000 tons in 1913; fell to 1,230,000 in 1920, and was about 1,480,000 in 1925. Tar comes chiefly from the Ruhr (945,000 tons). Gas works spread through the country give 460,000. Tar is generally distilled to the end. In 1924, however, the use of partially distilled tar was started on the roads to an extent of 3,000 tons. But this utilization is growing up. Germany is a large exporter of tar by-products, either as raw materials (pitch-creosote) or as intermediate or elaborate products.

United Kingdom—Tar production varies according to production of coke. Gas works give a regular return of 900,000 to 1,000,000 tons; production of coke ovens fluctuates between 210,000 (1921) and 712,000 (1923). Distillation is general, but part of the tar is utilized on the roads after partial distillation only. Quantity used in that way amounted to 270,000 tons in 1922, but reached 700,000 in 1925. During the actual crisis, distillation of coal is confined to gas works, and most of the tar produced has been utilized for road purposes. As England was a large exporter of pitch (over 200,000 tons a year) and of creosote, a shortage of these products occurred in the international market.

Switzerland—Production is quite small—30,000 tons a year from gas works. But as Switzerland is a very important dyestuff producing country, it seems important to point out that in 1914 that country exported practically all its tar and bought abroad chemical compounds obtained from tar distillation.

In 1915 however, Switzerland, which had large orders for dyestuffs, could not receive any quantity of necessary tar intermediates,

as adjoining countries had prohibited exportation of it. Switzerland was then compelled to erect distilling plants and to forbid exportation of crude coal tar.

Italy—We mention Italy, as a new regulation compels all tar producing plants the capacity of which exceeds 100 tons a year, either to remove from their tar, crude oils contained therein or to deliver it only to distilling plants.

France—Production amounts to 450,000 tons and is increasing. But quantities requested by Road Service increase more quickly: 10,000 tons in 1920; 50,000 tons in 1923; 100,000 tons in 1924; 135,000 tons in 1925; 190,000 tons in 1926. France has then an important deficit of tar, as distillation requests a minimum of 300,000. Even if France could distill tar to that amount, a surplus of 100,000 to 200,000 tons a year of pitch would have to be imported. These reasons explain why exportation of tar and by-products is strictly prohibited since 1920.

Ammonia

Ammonia is recovered from distillation gases, generally as sulphate of ammonia. Part, however, is recovered as ammonia solution utilized in Soda Works or for other purposes—but sulphate of ammonia means practically 90% of production. Until recent years, that was the only way to get sulphate of ammonia industrially to the amount of 15 Kgs. of sulphate per ton of coal distilled. Returns for 1925 give the following figures in thousand tons of sulphate of ammonia: United States, 664; United Kingdom, 430; Germany, 320; France, 120. Actual processes of synthesis are worked more and more extensively and we shall examine the economic situation resulting from that, but after having considered other sources of ammonia.

Benzol

Benzol is removed from distillation gases chiefly by washing it with oils (tar oils or paraffin oils or tetraline). Other processes may be used like refrigeration or absorption by activated coal.

Amount recovered can reach 10 kilograms per ton of coal carbonized.

Generally, removal of benzol is always made in by-product coke oven plants, but not in gas works. Prior to Auer's invention of mantles, it was almost necessary to keep benzol in gas so as to obtain a sufficient

illuminating power. Afterwards, condition of illuminating power of gas became less essential. But as town gas is sold at a relatively high price, it may happen that benzol will be sold by a gas company at better prices in the shape of vapor contained in town gas, than in the shape of liquid benzol after special treatment.

In 1915, however, calls for benzol, which is the raw material for getting pure benzene and pure toluene, were so large that removal of benzol from gas became compulsory in nearly all European countries. That rule was discontinued in 1919.

In England, two gas works, including by far the largest works in the world producing illuminating gas and coke, still remove benzol; in Germany the most important continue to do so.

In France and in Italy, removal of benzol has been made compulsory again by laws passed in 1923. Economic reasons for those measures will be found in the lack of gasoline in those countries.

German production of benzol amounted to 220,000 tons in 1924 (as against 195,000 in 1913). England gave in 1923, 160,000 tons—Belgium, 10,000 to 50,000—Bohemian State, 20,000—France, 50,000 (coke oven, 40,000—gas works, 10,000); that country imports 30,000 tons (10,000 from Germany, 10,000 from Sarre); United States reaches 400,000 tons.

Market for benzol has attractive prospects as the call for gasoline and substitutes is increasing more quickly than production. But benzol in France covers 5% only of motor fuel. Chemical uses of benzol, are, on the other hand, actually largely covered.

In addition to those products, it is necessary to mention that sulphur and cyanide are recovered, when purifying town gas; sulphur has been used for preparing sulphuric acid in large gas plants, Beckton for instance, and quantity obtained could reach quantity requested by sulphatizing of ammonia.

By-Products Special to Gas Industry

The Gas Plant has an excess of coke; generally coke obtained in small retorts is unfit for metallurgical purposes and is sold for domestic consumption; it is an excellent smokeless fuel. But generally housewives prefer to use anthracite coal, and advertising of coke is necessary. Recently new chemical uses have been developed; gas coke is utilized in the calcium carbide industry; it must be pointed out that

very often in Europe the same society owns the Gas and the Electric plant of a town. Calcium carbide fabrication may be considered as an excellent utilization of excess of electrical energy, as plants being always designed for peak consumption are obliged during the off hours to utilize in some way the excess of power. Calcium carbide fabrication means then, utilization of by-products of gas manufacture and of excess of power from generation of electricity. Carbide of calcium is the source of acetylene, which may be used for synthetic fabrication of acetic acid, etc.—other utilization is production of cyanamide, which is an excellent fertilizer and also a source of synthetic ammonia, production of which is measured in thousand tons as follows: Germany, 30; France, 50; Italy, 52. The total for the world amounts now to 700.

Another utilization of gas coke is to produce water gas, which as we said may be mixed with town gas. But that water gas has other objects, very attractive. By catalytic treatment, we can obtain synthetic methanol (read Gen. Patart's paper). Water gas is also raw material for synthetic ammonia in certain processes.

Furthermore water gas in certain other catalytic processes is a source of synthetic petroleum. (Read Professor Fischer's paper).

Those indirect uses of the most important by-product of gas industry are quite new but are watched with the greatest interest.

BY-PRODUCTS SPECIAL TO COKE INDUSTRY

Coke producers have as a special by-product the ordinary town gas—they may sell it to adjoining works, to glass works for instance, but they may also consider gas as a mixture of chemical gaseous compounds. The composition of town gas is roughly:

Hydrogen	45 to 55%
Methan	20%
Ethylene and similar	1 to 2%
Carbon monoxide	5 to 6%
Carbon dioxide	3%
Oxygen, nitrogen	12%

The first idea is to consider that mixture as a source of hydrogen and to utilize hydrogen for catalytic production of ammonia. We must then provide for preparation of hydrogen.

Chemical process of absorption of impurities has been used; but preference may be given also to the physical separation by way of

refrigeration (Claude's method) and hydrogen is obtained with 1 or 2% of carbon monoxide.

To make synthetic ammonia, nitrogen must be mixed with hydrogen; the source of nitrogen is air—oxygen may be eliminated by way of refrigeration, and this process is economical if pure oxygen is wanted (explosive for iron mines) but generally oxygen is burned with hydrogen in excess—part of hydrogen is in this process wasted. Catalytic plants are of various systems Haber—Casale—Claude—Fauser. Generally speaking ammonia made is used in the shape of sulphate of ammonia as a fertilizer. It requires sulphuric acid; except if anhydrate is available (case of Billingham Works). But it is possible also to make from that ammonia nitric acid by the Kuhlmann's or Oswald's reactions—in 1917 consumption of nitric acid reached 1800 tons a day in Germany; 1000 in France. Sometimes also, ammonia is transformed into urea which is an excellent fertilizer.

Actual development of that method may be described as follows: Haber process is used by the Badische at Oppau and Merseburg. Annual output is (estimated in nitrogen) 330,000 tons. In this case, synthetic ammonia is not really a product of coke ovens, but also of water gas.

Fauser's process is worked by the Montecatrini Company in three works of Novare (15 tons of nitrogen a day) Meran (20) and Coghinas in Sardinia (Hydrogen comes really from electrolysis of water).

Claude's process is found in France:

	Tons of nitrogen per day
Bethune	28
Aniche	14
Decazeville	5
St. Etienne	5
Grande Paroise	1
also Belgium: Ougree	21
Italy (Azogeno)	5
Spain	7
Japan (Oshima)	5

Casale's process is used in

	Tons per day
Italy	50
Belgium Solvsy (Ostende)	50
Japan (Neobeka)	100
Spain	15

and France-St. Auban	4	(electrolytic hydrogen
Dourges	15	
Lehs	25	(in course of
Noeux	25	achievement)
Anzin	25	"
Carling	25	"
Engrais azotes at Soulon	37.5	"
Roche La Moliere	15	"

This process will also be used at the national works under construction at Toulouse for 160 tons a day. At Anzin, ammonia will be partly at least, utilized for making nitric acid and not sulphate of ammonia.

Carbon monoxide gives a catalytic reaction with hydrogen and does not poison the catalytic agent as it was thought a few years ago; and when hydrogen is impure and contains carbon monoxide, methanol will be found at the same time as ammonia, as it was said by General Patart. This assertion has been verified.

With ethylene, ethanol (ethylic alcohol) is easily obtained (De Loisy's process)—a ton of coal can hence give 10 litres of ethanol. methane may be utilized as an addition to water gas, as it possesses a heating value above the average.

COAL, SOURCE OF FERTILIZERS

We found various stages of treatment that from coal we could obtain ammonia, synthetic ammonia and cyanamide—which means nitrogenous fertilizers. That subject will be discussed in another section. But it is necessary to point out that cyanamide is by itself a fertilizer, when ammonia must be transformed into sulphate, urea or in another kind of fertilizer, which requires additional substances to be used.

From an economic point of view it is interesting to see whether those fertilizers may be used to a larger extent than now. The question has not the same importance in America where the density of population is comparatively small and the soil is not exhausted as in Europe, a country over crowded with a soil exhausted by so many hundred years of intensive cultivation. Advertising has brought about an increase of consumption and has to be continued in several countries like France, Spain, Italy, etc. Consump-

tion of fertilizers may be compared in 1913 and 1924 for Belgium, Germany and France.

	Belgium	Germany	France
1913 Ton of Nitrogen per sq. Km...	0.69	0.41	0.15
1924 " " " " " " ..	1.36	0.65	0.17

These figures show how consumption can be increased in Germany, in France and more even in Italy, so as to reach the Belgian level. It seems interesting to point out that utilization of fertilizers is in relation to the density of population.

Low Temperature Distillation

We have spoken chiefly of ordinary distillation. Few words will be said about low temperature carbonization as this will be discussed in another section. From an economic point of view, it is necessary that the value of the solid obtained must be similar to the value of coke obtained in high temperature process.

Hydrogenation

Another way of treating coal is hydrogenation. It has been considered in Dr. Bergius' paper. We may mention in addition that hydrogenation of naphthalene enables us to transform that solid into liquids (Tetralin—Decalin) which may be used either as a substitute for turpentine or mixed with benzol and alcohol as a substitute for gasoline. But as naphthalene is a material scarcer than gasoline (we can recover it to an extent of 8% maximum of the tar), it must be considered only as an eventual additional source of motor fuel.

Summary

We have endeavored to show how many chemical products are obtained from coal. We must however point out that all operations must be made in large plants to be economically possible. In the country of mass production it seems evident that in proportion as we successfully treat by-products on a large scale the problem of this disposal becomes less difficult. For these reasons it has been necessary for instance to concentrate tar distillation in larger works, in preference to having it spread in small units. Examples can be given in Germany, Belgium, England and even France.

It is on the other hand unnecessary to have all of these successive products made by the same company; it is possible to switch from one

production to another, and if a company would devote its activity to successive productions of all products of such a chain, it would be quite dangerous in case of a crisis—if a link is missing, the chain is destroyed.

Laboratories

We shall now give information about researches made in France. Private companies with laboratories, for instance Kuhlmann, Claude, Ales-Froges la Camargue, Gay de Paris and collieries like Carmaux, Noeux, Lens, etc.—Universities have laboratories devoted to such studies. Paris (M'Mailhe) Strasbourg.

We must also mention a collective laboratory—that is the National Society for Researches in Fuel. Half of the expense is paid by the Government, a quarter by the Collieries Owners Association, the fourth quarter being paid by the Steel, Tar, Chemical, Petroleum and Shale Associations. This is an example of cooperation of the Government with the professional associations.

Conclusion

The conclusion of this paper will be that coal gives by chemical treatment useful products—even excellent fuel, liquid, gaseous or solid, and if in the successive transformations we lose a part of the initial heating value, efficiency of these new products is higher than the efficiency of the crude coal burned on a grate; and we have no final disadvantage from the point of view of heating value. On the other hand, we have won chemical compounds of considerable interest.

Financial results vary very much from one country to another, and even vary with the time; calculation must be made then according to local and actual conditions.

But general interest is such that it will be perhaps necessary in the future to prevent the use of crude coal without any treatment. This opinion has been expressed by Mr. Lander. It has been even proposed at a meeting of the French Commission for Coal Utilization by General Patart. He gave the financial scheme, which could have been effective; but certain causes have led to postponement of execution of this scheme.

In Italy, on the other hand, such a scheme seems to be foreshadowed in the arguments presented (July, 1926) by the Government for

establishing a Commission of Research for better utilization of fuel.

The United States are very rich in everything, but it seems that many realize that such a conclusion has to be adopted more or less rapidly; and instead of the Hoover slogan, "Sugar will win the war —don't waste it," a new slogan has to be adopted: "Coal will win life—don't waste it!"

THE INSTANTANEOUS CARBONIZATION OF CRUSHED COAL

By Alfred H. White

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This paper describes tests on the carbonization of crushed coal while falling freely through a vertical retort heated externally to a red heat. The use of the word "instantaneous" in the title is not strictly correct, for a measurable time is required for this process. The time is, however, only a fraction of a second in some cases and never more than a few seconds, so that in comparison with any of the methods of mass carbonization, it is relatively instantaneous, and the term is more accurately descriptive of the process than any which has been suggested.

The idea of producing gas by dropping powdered coal through a hot retort is not new. Bassett in 1871 secured U. S. patent 118,579 for such a process of manufacturing illuminating gas. He specified that the coal should be an impalpable powder and recommended a retort 38-40 feet long and 15-18 inches in diameter. Various inventors in the United States and in other countries have since patented variants of the process. None of them give any data from which the performance of the process can be judged, and so far as is known to the writer, no details have been published at any time.

Whitaker and Suydam* reported some tests on dropping crushed Pennsylvania gas coal through a retort four inches in diameter and six feet long, heated to various temperatures. They state that some of the powder stuck to the walls of the retort, and it is not possible to learn from their work how much of the gas was produced while the coal was falling freely and how much was evolved from the coal after it had stuck to the wall of the retort. They do not make any statements on the composition or character of the coke.

This summarizes the prior work which was known to us when experimental work was commenced in 1922, as part of the program of co-operative research work which has been maintained at the University of Michigan by the Michigan Gas Association since 1900. The

*Journal Ind. & Eng. Chem., 10, 431, (1918).

experimental work was performed by Don M. Herringshaw, Howard G. Chamberlin, and Richard E. Townsend.

Experimental work was commenced in a furnace made from a nichrome tube 2 inches in diameter and 27 inches long, heated electrically and mounted vertically. Crushed coal was fed from a reservoir by a worm feed, and the coke was caught in a receiver forming a prolongation of the heated tube. Experiments with Elkhorn coal showed that even with this short tube it was not necessary to use the finely ground coal specified in the patent literature. With the tube at 1750-1850°F., coal as coarse as 14-20 mesh was carbonized to a small extent, and finer coal was carbonized more completely. There was some tendency for the coal to stick to the walls of the tube, but the coke which passed through the tube without sticking and was collected in the receiver differed from anything which we had seen before. It consisted of individual puffed irregular granules, usually spheroidal. Sometimes, especially with the finer sizes of coal, the coke consisted of aggregates of fine granules. We named this material bubble coke. Table I contains the results of tests in which no large amount of coke stuck in the tube. The coal was fed at a low rate and hydrogen was passed through the tube to sweep out the gases and prevent excessive cracking. Both the volume and the heating value of the hydrogen have been deducted from the figures reported in Table I. There is a possibility that the composition of the gases was affected by the hydrogen, but the work is not accurate enough to show whether this is the case. The later series of tests reported in Table III did not use any hydrogen or other foreign gas.

These results were obtained prior to the publication of the paper by Newall and Sinnatt* in 1924.

They gave the name "cenospheres" to what are apparently substantially the same type of products as the bubble coke which we obtained. The following quotation from their work illustrates this:

"When a particle of a coking coal (60-90 mesh) is allowed to fall two or three inches into an inert atmosphere at temperature of 600° C., the formation of a cenosphere begins and an increase in volume occurs as the particle descends, whilst a considerable quantity of volatile products is evolved. In passing through a heated zone of 18 inches, particles of a clarain, measuring 0.34 mm. average diameter were con-

*Newall & Sinnatt, "Carbonization of Coal in the Form of Fine Particles—Fuel in Science and Practice," 3, 424, (1924).

verted into cenospheres of 0.54 mm. diameter, the respective volumes being in the ratio of 1 to 4."

TABLE I.

Data on Instantaneous Carbonization of Elkhorn Coal while Falling through a Tube 2" Diameter and 27" Long, Heated to 1750-1850° F.

Coal Contained 36.0 Percent Volatile Matter

Test No.	Size of Coal Mesh	Volatile Matter in Bubble-Coke	Volume Gas Cu. Ft. per Lb. Coal	Heating Value of Gas. B.t.u.	B.t.u. in Gas per Lb. of Coal
H2	thru 100	12.2*	8.3	420	3550
H4	65-100	12.3*	7.0	405	2820
H12	35-48	6.4	7.3	487	3550
H13	35-48	5.3	5.5	487	2710
H16	20-35	10.4	5.1	591	3100
H17	20-35	10.1	5.3	512	2640
H18	20-35	21.5	4.7	601	2840
H19	14-20	27.0	2.4	419	1020
H20	14-20	28.3	2.2	465	1022

*Volatile matter in coke probably high because of loss of dust from fine powder while determing the volatile matter.

This first furnace gave a good deal of trouble because of stoppages due to coke adhering to the top or bottom of the heated zone. It was thought that this was due to the cementing action of coal still sticky because of incomplete carbonization and that a larger tube would be better. A furnace containing a tube 3 inches internal diameter with a heated length of 84 inches was then built. This sometimes gave trouble with deposits of coke, but when the tube was evenly heated and properly handled the coal dropped through without sticking to the walls and was collected as loose particles of coke in the receiver. This longer furnace when operated at 1500° F. gave results quite similar to those with the smaller tube at 1800° F. The time required to drop through the tube can only be approximated, for the fine particles probably swirl as the gases are given off, and their rate of fall cannot be calculated from the laws of falling bodies. In accordance with the laws of gravity, the time of passage, even through our largest tube, would be only about two-thirds of a second.

The air-dried coal was crushed and screened in order to study the

influence of size on the time of carbonization. It was fed continuously by means of a worm. The gas and coke were collected, but no attempt was made to recover tar or ammonia. The larger tube proved to be a defective casting and developed a bad spot which necessitated cutting about a foot from the middle of the tube and welding the pieces together so that the heated portion became only about 72 inches long. In the last series of experiments, the heated length was only about 60 inches.

Four different coals of three widely different types were used for test. The analyses are given in Table II.

TABLE II.

Analyses of Coals Used in Tests

	Elkhorn No. 2	Illinois No. 1	Illinois No. 2	Lignite
Moisture	0.4	4.2	3.1	10.7
Volatile	36.0	37.0	47.4	40.9
Fixed Carbon	59.9	51.4	44.9	41.7
Ash	3.7	7.4	4.6	6.7

The Elkhorn coal came from the stock pile of the Washtenaw Gas Company. Illinois coal No. 1 was a sample of uncertain origin which had been in the laboratory about two years and had probably oxidized through exposure to the air. Illinois No. 2 was a fresh sample of coal from Number 6 seam near Catlin, Vermilion County, obtained through the courtesy of Professor S. W. Parr. The lignite was from South Dakota and of uncertain origin. It had been in the laboratory nearly two years.

The results of the carbonization tests are given in Table III and are arranged for each coal in order of decreasing fineness. It will be noted that the volume of gas per pound of coal is usually greatest with finely powdered coal and that when coal as coarse as 14-mesh is used only a small portion of the volatile matter of the coal is driven off, and a correspondingly small yield of gas results. If a longer tube and a higher temperature had been used, coarser coal could have been handled. The heating value of the gas is never high for coal gas and is usually lower than with present retort practice. This is because of cracking due to the relatively long time that the gas remained in contact with the hot walls of our laboratory tube. The total energy

TABLE III.

Data on Tests of Instantaneous Carbonization

Test No.	Coal Used	Size of Coal	Size of Furnace	Volatile Matter in Dry Coke	Vol Gas cu. ft. per lb. of Coal	Heating Value of Gas B.t.u.	Bt.u. in Gas per lb. of Coal	Temp. of Retort °F
T25	Elkhorn No. 2	28-40	3"x84"	5.5	6.3	480	3080	1475
T3	Elkhorn No. 2	20-28	3"x84"	3.4	7.5	423	3160	1655
T8	Elkhorn No. 2	20-28	3"x84"	10.1	3.7	463	1720	1300
T4	Elkhorn No. 2	14-20	3"x84"	7.3	5.0	575	2870	1210
T27	Elkhorn No. 2	14-20	3"x72"	20.3	3.8	444	1710	1655
T11	Elkhorn No. 2	10-14	3"x84"	17.9	3.25	614	1995	1390
T18	Illinois No. 1	20-28	3"x72"	12.5	2.7	525	1420	1390
T21	Illinois No. 1	20-28	3"x72"	16.4	4.45	480	2160	1475
T31	Illinois No. 2	65-dust	3"x72"	11.7*	8.3**	424	3518**	1475
T30	Illinois No. 2	28-65	3"x72"	10.7	7.0**	474	3318**	1475
T29	Illinois No. 2	20-28	3"x72"	29.7	5.4**	501	2705**	1475
T28	Illinois No. 2	10-20	3"x72"	39.6	2.7**			1475
T24	Lignite	28-40	3"x60"	21.1	7.5			1390
T23	Lignite	20-28	3"x60"	37.9	4.5	355	1580	1390
T22	Lignite	14-20	3"x60"		1.75			1390

* Volatile matter in coke probably high because of loss of dust from fine powder during determination of volatile matter.

** One of the heating elements of the tube was burned out during these tests causing a black spot near the bottom of the tube. Some coke stuck in this part of the tube, and the gas yields are, therefore, too high. The determination of volatile matter in the bubble coke was made on that portion which dropped through freely.

delivered to the gas as expressed in B.t.u. per pound of finely ground coal is as high as in commercial practice. If the coal is so coarse that a material amount of volatile matter is left in the coke, the energy delivered as gas is necessarily decreased.

Type of Coke Produced

The coke from the Elkhorn coal and that from the Illinois coal is composed of small grains which under the microscope appear as glistening irregular black bubbles, reminding the observer of the appearance of fritters, which have been coated with an asphalt varnish. Broken granules showed hollow globules or a coarse, sponge-like structure. Coal finer than 20-mesh produced this bubble coke quite uniformly. Coal of 14-20 mesh showed a number of particles fused only on the edges and with the centers unchanged. Coal of 10-mesh appeared practically unchanged after its passage through our apparatus. The volatile matter of this instantaneous coke varied from 3.4% to a figure almost as high as that of the original coal. When the volatile matter of the instantaneous coke was determined in the usual way, the appearance of the resultant residue was always noted. With Elkhorn coal a reduction of the volatile matter to 15% destroyed the coking property of the instantaneous coke. With 18-20% volatile in the instantaneous coke, hard, firm, and dense buttons were obtained, and with higher volatile matter, puffed buttons were obtained comparable to those from the original coal.

The bubble coke from the freshly-mined sample of Illinois coal was puffed more than that from the Elkhorn coal. In the determination of volatile matter in the original coal with 47.4% volatile, soft and puffed buttons were left in the crucible. The bubble coke with coke with 29.7% volatile yielded dense and silvery buttons, while that from the coke with 11.0% of volatile matter did not give a coherent button.

The instantaneous coke from the lignite was entirely different from that from the Elkhorn or Illinois coal. It showed no evidence of fusion and could hardly be distinguished under the microscope from the raw coal, although it was somewhat cracked and porous. None of the instantaneous cokes from this lignite sintered at all when volatile matter was determined. It should be remembered

that this coal had been stored two years before testing and that a fresh sample might have behaved differently.

TIME AND TEMPERATURE REQUIRED FOR CARBONIZATION

The effect of prolonged heating to moderate temperatures without access of air has been tested by various investigators. One of the earlier reports* from this laboratory showed that with five widely-different American coals the evolution of gas was not evident even after several hours until a temperature of about 570°F. was reached. At 840°F. Pittsburgh gas coal fritted together, and if the fritted mass was powdered and reheated, it was found that the coking property had been destroyed completely. Only about 1.0 cu. ft. of gas was evolved per pound of coal while raising the temperature to 840°F. during several hours. In our present experiments the quantity of gas and the puffed condition of the coke indicate that the coal finer than 14-mesh must have been heated higher than this temperature while dropping through our hot tube. There does not seem to be any evidence to tell what higher temperature was reached.

Newall and Sinnatt showed that when a tube 1.5 inches internal diameter was heated to 1112°F. for a length of 18 inches cenospheres were formed, but they did not attempt to estimate what temperature was actually reached by the coal particles. They noted that particles of coal of 10 to 30-mesh fell through a cold tube 28.5 inches long in 0.6 seconds, while particles 60 to 90-mesh required 1.8 seconds to fall the same distance. They also observed that these figures, obtained in still air, could not be considered as significant of the conditions prevailing in the hot tube.

Attempts to calculate the rate of heating of the particles have also been futile. The particles dropping through a tube would be heated by convection and radiation. It may be calculated that a cube of coal 1-50 of an inch on a side will receive enough radiant energy in one second to heat it to 700°F., but particles of coal of twice these dimensions have evidently been heated to a higher temperature than this in our retort so that convection probably plays

*"Destructive Distillation of Coal at Low Temperatures," White, Park, and Dunkley, Proc. Michigan Gas Assn., 1908, pp. 83-109.

a material role. The exothermic reaction developed above 400°F. may also be responsible in a considerable measure for the unexpectedly rapid heating of these relatively coarse particles.

Application of Process

There seems to be a rather general opinion that a soft semi-coke of 10-15% volatile matter is well adapted for pulverized fuel in power plants. This bubble coke, with its soft, thin walls and controllable volatile matter would seem to be especially desirable for this purpose. Its weight is only about one-third that of an equal volume of coal, and it is so soft that it crumbles between the fingers and yields scale-like particles with a maximum of surface, and apparently well adapted to rapid combustion.

The possibilities of this process may be seen from Table III, but a single test may be given here in somewhat more detail. Elkhorn coal, crushed and sized for experimental purposes to pass a 14-mesh and be retained on a 20-mesh sieve, was dropped through the 84-inch tube heated to rather low red heat, 1210°F. No coke stuck in the tube. The weight of bubble coke in the receiver was 78% that of the air-dried, and it contained 7.3% of volatile matter. The yield of gas was 5.0 cu. ft. per pound of air-dried coal, and its heating value was 574 B.t.u. per cubic foot with a total heating value of 2870 B.t.u. in the gas from one pound of coal. No data were taken on the yields of tar and ammonia.

The yields of gas from the Iliinois coal No. 2, as given in Table III, are somewhat too favorable, due to uneven heating of the tube which caused some coke to stick and to be given a longer carbonization than it would have received had it dropped freely. The volatile matter of the coke was, however, determined from that portion which fell freely, and so the applications which are to follow are not affected. The original coal was feebly-coking. When the volatile matter was reduced from 47.4 to 29.7 it became a coking coal which yielded dense and silvery buttons in the usual test for proximate analysis. It seems, therefore, possible that dense coke may be made from some high volatile coals by subjecting them to a preliminary treatment by instantaneous carbonization under prop-

er conditions, followed by a coking process in the usual ovens, with recovery of merchantable gas in both stages.

PROBABLE CAPACITY OF COMMERCIAL UNITS

It should be emphasized that the results reported in this paper are of laboratory tests and that any attempt to forecast the behavior of the process on the commercial scale involves a considerable element of speculation. However, some consideration of the probabilities is in order. The capacity of our laboratory retort was limited by the capacity of the scrubbers and meters for the gas. Changes were made in the later tests to permit more gas to be treated than in the earlier tests. Tests 25 and 27 on Elkhorn coal may be cited as instances of the greatest capacity we were able to reach. In test 25, 2.3 pounds of 28-40 coal were fed in 30 minutes, 14.5 cu. ft. of gas being made and 62.6% of bubble coke, with 5.5% of volatile being collected in the receiver. In Run 27, 2.0 lbs. of 14-20 coal were fed in 25 minutes, 7.7 cu. ft. of gas being collected and 72.2% of bubble coke with 17.9% volatile being found in the receiver. No attempt was made in any of our tests to determine the amount of coke carried with the gas as dust, nor, as stated before, was the tar collected. Even in test 25 the hot gases probably stayed in the retort 10 seconds so that there was considerable secondary cracking of the gas. As stated before, the limitations of the scrubbing and metering equipment at hand prevented tests at a more rapid rate.

The capacity of a retort may be approached from another angle—that of possible heat transfer. In the usual retorts and coke ovens the heat transfer is almost wholly by conduction, first through the wall of the retort and then through a continually increasing thickness of coke. In this instantaneous process heat is rapidly transferred from the inner wall of the retort by convection and radiation. The transfer by radiation is large. There are too many unknown factors to attempt a numerical solution of the problem. It seems possible, however, that the limiting factor in capacity of retorts of this type may be given by the velocity of the gas rather than the ability to transfer heat to the coal. If the gas is taken off the top of the retorts the velocity must be kept fairly low to avoid too much loss of dust. In our later experiments we took the gas off the bottom of the retort, and it should be possible by providing dust catchers and by using coarser sizes of coal to work with high gas velocities in the retort.

The size of possible commercial units is also largely a matter of speculation. So far as transfer of the radiant energy is concerned, the diameter may be as large as desired. The turbulence of the gas stream and hence the transfer of heat by convection will also increase with the larger amount of coal fed into a large pipe, so that here again there does not seem to be any definite limit in size indicated. Commercial limitations of cost of castings would probably prevent the diameter from exceeding 18 inches.

SUMMARY

The tests described have shown that coal as coarse as 14-mesh will undergo material destructive distillation when dropped freely through a vertical retort seven feet or less in length and heated to from 1200 to 1600° F. The coke formed consists of bubbles or aggregates of puffed spheroidal particles and may be made to contain from 5 to 20% or more of volatile matter, depending upon the fineness of the coal fed into the retort, and the temperature and length of the retort. The bubble coke is so soft that it pulverizes readily between the fingers, and it should, after grinding, make an excellent powdered fuel. The quality and quantity of gas will be controlled by the same factors as control the properties of the coke. With fine coal the yield of gas may equal that now obtained by carbonization in mass, but the percentage of volatile matter in the bubble coke will then be low. Some coals with high volatile matter have their coking properties improved by this rapid distillation with reduction of their volatile matter to about two-thirds of the former value. It indicates the possibility of making a dense coke in a two-stage process, with recovery of gas in both stages, the retorts for instantaneous carbonization being perhaps heated by the waste heat of the coke ovens. The most obvious application would seem to be to a steam power plant, burning powdered fuel, which is so situated that it can sell the gas produced as a by-product. It is believed that from the operating standpoint it will be more advantageous to carbonize the coarsely crushed coal and pulverize the bubble coke than to pulverize the coal to dust before carbonization.

DISCUSSION

FRANK F. MARQUARD.* My remarks will be confined to personal experiences I have had in making high temperature coke. High temperature† coking, the way I understand it, ranges between sixteen

*Assistant General Superintendent, Carnegie Steel Co., Clairton Works.

(†Mr. Marquard here refers to a range of temperature suitable for metallurgical coke, and not to true low temperature distillation.—Ed.)

hundred degrees and twenty-one hundred degrees Fahrenheit. Within a very few years, most of the by-product plants have been coking around eighteen hundred degrees. The coal that we are mostly interested in at Clairton is Klondike coal, which averages 32% volatile matter, 58% carbon, 9% ash, and 1¼% sulphur.

In the early history of the production of by-product coke for metallurgical purposes in this country, it was considered quite essential that a certain percentage of low volatile coal be added to the high volatile coal in percentages ranging from 20 to 25% in order to get a coke sufficiently hard to give a satisfactory blast furnace coke, and while we found that the low volatile coal did give a more blocky coke, yet, owing to the high freight cost to bring low volatile coal in to the Pittsburgh district, and the low yield of by-products from the use of low volatile coal, we began an extensive investigation to find out how we could eliminate Pocahontas coal and make a good metallurgical coke and now we are using one-hundred percent high volatile coal.

I was in charge of the first work done along this line at the Farrell by-product plant in 1907, and it was at this plant that we developed coke which while somewhat more fingery in appearance, made as good quality coke as the mixed coal, and worked about as well in the furnace as the coke we had previously made, with a mixture of 20% Pocahontas coal; but we soon discovered that we had to maintain very much closer control of the heating conditions of our ovens when we were operating on 100% high volatile coal.

We gained enough information to convince myself and our officials that we could make a good metallurgical coke from 100% high volatile coal, and the large by-product coke oven plant at Clairton, on the Monongahela River, 20 miles south of Pittsburgh and about 30 to 60 miles from the coal mines, was built with the purpose of using 100% high volatile coal.

All of the mines supplying coal to Clairton are located along the Monongahela river and the coal is all delivered to Clairton by water.

The Clairton by-product coke plant, when present construction is completed, will consist of 1,482 ovens, having a coking capacity of from 29,000 to 30,000 tons of coal per day. This is very much the largest by-product coking plant in the world.

The first installation of ovens was completed in 1918, and all of the ovens have been operating 100% continuously ever since their completion.

We have progressed in the coking of 100% high volatile coal for metallurgical coke, and have made a great deal of headway since these ovens were in operation.

I might say that we have overcome quite a bit of prejudice of the superintendents, who have sometimes insisted on percentages of Poca-

hontas coal, but the price was so high that we could not figure out where we would come out to any advantage with the addition of Pocahontas coal.

Our largest ovens have a capacity of 20 tons of coal per charge, with fine operating flexibility and perfect control of the heat distribution, so essential to the production of uniform metallurgical coke.

Situated as we are, supplying coke to about 25 blast furnaces, we have been in constant touch with furnace operations as reflected by every change that was made in our oven coking operations.

Coke quality has been frequently blamed for poor blast furnace operations all over the country. This has been due largely to the fact that there has been no satisfactory method developed, which will accurately indicate coke quality for blast furnace performance. Therefore, it always was possible for the furnace man to blame the coke whenever his furnaces were not producing properly. So, while our coke was produced at a very low cost, we were not so greatly concerned even if our blast furnace tonnage was not up to that of some of the other large furnaces which were using coke made from a mixture of 20% Pocahontas and 80% high volatile coal, and the feeling was for a time "let good enough alone," but two years ago last March we decided to conduct a series of experiments over a wide range of coking time and temperatures at Clairton to see what could be done.

A well known coke oven engineer, I remember, had made a tour of this country the year before and gave out much information about how he succeeded in increasing the combustibility of coke by lower temperature coking, and even went so far as to claim that coke with 2½% volatile matter would have a higher rate of combustibility, and would drive faster in a blast furnace; and strangely enough, several of the smaller plants which use Pocahontas Coal have succeeded in increasing their furnace practice with this low temperature coke.

Thus, at a general conference, it was agreed to lower the coking temperature in stages and observe the operation of the 24 blast furnaces using Clairton coke.

Our normal coke temperature averaged 1800° F. We accordingly lowered it to 1750° F., then to 1700° F., then to 1650° F., then to 1600° F., until our coke volatile came up to 1.75% as compared with 0.77% on the 1800 degree coke and 0.42% on the 2100 degree product. But with each lowering of the temperature the daily production of iron from our furnaces was reduced and the pressure increased, and in general, the operation of all furnaces were very much less satisfactory.

This experiment over a period of two months on a large number of furnaces told us one big story, that the coking temperature of Klondike coal had a very important bearing on the coke quality and a great deal to do with production, so we put the temperature back up to 1800° F.

Now in view of the poorer coke quality on lower temperature, we decided to step up the temperatures and observe the coke quality and blast furnace practice at higher temperature, so accordingly we gradually stepped up the temperature to 1850° F., then to 1900° F., to 1950° F., to 2000° F., to 2050° F., then to 2100° F., and with each increase in temperature we observed a better working condition of the blast furnace, with increased tonnage.

Twenty-one hundred degrees Fahrenheit is as high as we could carry our coke temperature with safety for with 2100° F. coke we would have a temperature at the airports of 2750° F. at the time of reversal. By the way, we took these temperatures with an optical pyrometer. We had a pyrometer man who continually took temperatures of the airport and of the coke daily, and our coking practice is guided by the pyrometer readings from day to day. We also discovered that coal from about the same district having about the same analysis as far as volatile matter, fixed carbon, ash, sulphur, is concerned, showed different coking characteristics; also that their resin content varied from 18 to 31% resin. We, therefore, classified these coals according to their coking properties and used these coals separately in our ovens. We found that if we had a coal with a uniform resin content, we could use it safely.

So great has been the improvement in our blast furnace practice by the use of Clairton high temperature coke, that the corporation record of production was made on one of the Carnegie blast furnaces at Edgar Thomson, Blast Furnace "H," last month, which produced 25,627 gross tons of pig iron for the month of October. This is 823 gross tons per day on a coke practice of 1,825 pounds per gross ton of pig iron.

This remarkable furnace performance was made by the use of all Clairton by-product coke made from 100% high volatile Klondike coal. coked at a temperature of 2080° F.

CECIL H. LANDER. Before saying anything about the paper on the instantaneous carbonization of crushed coal, there is just one point I would like to make in connection with Mr. Bing's most interesting paper. It is really a minor point, but I feel that it is a mistake to choose the tonnage of coal carbonized as the basis when comparing high and low temperature carbonization from the point of view of a gas undertaking. The comparison should be made on the basis of equal output of gaseous therms. Such a comparison shows more clearly the changed relative importance of the various products and the resulting financial effect. I have heard quite a number of fallacious arguments based on the cost of carbonizing a ton of coal, where the tacit assumption has been made that the same gross profit per ton will produce the same financial effect on the undertaking, even when it has not also

been assumed that the carbonizing and overhead costs are the same in the two cases.

I have been very interested in Mr. White's paper, and by a coincidence I have with me a few slides which I should like to show. These slides are microphotographs prepared by my colleague, Mr. Sinnatt, and illustrate the results he obtained from experiments very similar to those of Mr. White, and which he first described in 1922. The cenospheres shown on the slides were obtained by dropping the powdered coal through an inert atmosphere, and all show a hollow, more or less spherical structure—hence the name "cenosphere." The interesting point is that they all consist of a lattice-work frame, the windows being covered with a thin transparent skin. The windows contain small specks which Mr. Sinnatt has designated tertiary structures.

Mr. Sinnatt has been interested in making a collection of cenospheres showing the same typical structure, and has collected them from the dust issuing from a cement works, in an express train, from a pulverized fuel station, and from the deck of a channel steamer, he also got quite a number. In many of these cases a number or all of the "windows" had been burned out, leaving the lattice-work frame. This seems to indicate that cenospheres may be formed as an intermediate step in the combustion of particles of coal.

At the present time he is making experiments using vertical retorts about 20 ft. high, the temperature of which can be varied in various zones or can be uniform throughout the whole 20 ft.

I have been extremely gratified to listen to Professor White's most able exposition of his subject and to note how two investigators on either side of the Atlantic working independently have obtained very similar results.

6532—16 Ph

MR. J. R. CAMPBELL.* I judge that most of you heard Dr. Lessing's talk this morning, and I wish to call particular attention to something he said that has not been done in the United States to any great extent. I refer to the subject of the washability study of coal for metallurgical purposes. I think that it has been sadly neglected in this country, that it, a complete study of the coal, especially of the lower productive measures, which, as I take it, are going to be the coking coals of the future. You know there are a lot of good coking coals in Central and Western Pennsylvania that are suitable for by-product purposes, and a complete study of these coals can be made, showing the recoveries, the sulphur reduction, the gravities, etc. I was particularly interested in having Dr. Lessing mention that point, because it has only lately been brought to the attention of the coal operators in this country.

I had occasion recently to make some studies of the lower productive measures in Central and Western Pennsylvania, and we found

* Bituminous Representative, American Rheolareur Corporation, Scottdale, Pa.

that these coals, running 3% sulphur, can be easily reduced to metallurgical coal by modern processes of cleaning. This is the one point I wanted to bring out and to emphasize that we have potential coking coals in Central and Western Pennsylvania which can be treated by modern systems of cleaning, and to which we should apply modern systems of study.

I think that I myself have been a pioneer in this work, having worked with it years ago, but it is only lately that a complete study of the coal is being made, as Dr. Lessing pointed out.

WALTER S. LANDIS.* In line with the remarks of the last speaker, about a month ago I had occasion to visit a coking plant in Europe. The coke produced was taken by a single customer on rather rigid specifications:—ash not over 4½%, moisture as shipped not more than ½%.

The coal from which the coke was produced was a mixture of fines from a modern washing plant and the slate from the jigs. This mixture was ground to 100 mesh and passed through a modern oil flotation plant of Minerals Separation type. The feed containing about 16% ash yielded a coal of only 3½%, a remarkable performance for any dressing plant.

The fine coal was separated from the water in filter presses (labor was only 65 cents per day) stamped into forms and charged into the ovens in a block.

The coke produced was a remarkable product, extremely hard and uniform in size of pieces. This is an example of what can be done in the dressing of coal by modern methods.

E. A. MUNYAN.† I wish to refer to Mr. Campbell's remark with respect to the high grades of coal. I happen to be an ex-gas man, now in the coal business. If this meeting does nothing else, it will have a great effect on the coal and gas business of this country, if, certain standards of coal, or qualities of coal are thought about and considered and studied, because the coal men at the present time and in the last three or four years have been at a very serious disadvantage. They have not been able to spend any money to any considerable extent on experimentation, or on any equipment for preparing the coals much better than they had been prepared in the past. And when the coal man demands five cents, ten cents or fifteen cents a ton for coal that is better prepared, the coal buyers throw up their hands; they will not pay the few extra cents per ton. I think you will find in ninety-nine cases out of a hundred that if this extra money is paid you will get much better coal.

This deserves some study. I think if the other coal men present were to be asked, they would say the same thing. The coal industry, the gas industry and the coke industry are all very much linked

*Vice President, American Cyanamid Co., New York, N. Y.
†Sales Engineer, Logan County Coal Corporation, Cincinnati, Ohio.

together. It would be a good thing that this matter be taken up at some future time. Many would like to have it taken up; some of course are only interested in profit, but I believe the majority are interested in the better preparation of coal.

CHAIRMAN W. L. AFFELDER. Answering Mr. Campbell's remark regarding the ability to make metallurgical coke out of coal of such quality as has heretofore been considered outside the pale, I might say that it is not advisable for any coal operator to become over-optimistic about the possibilities of his off-grade coal before making some very exhaustive tests and before going into any considerable expense for equipment.

It is true, as Mr. Campbell said, that three and a half percent sulphur coal can frequently be washed down to such a point as to make good metallurgical coke, but there are certain kinds of coal in the lower measures,—not only certain kinds of coal but coal in certain portions of the seams,—which analyze better than coal from other portions of the same seam, and which have entirely different washing characteristics, in consequence of which the results will be extremely disappointing. It is not a fact that every coal with certain objectionable constituents can be made an exceptionally good coal if the specific gravities of the objectionable factors are such as to prevent ready separation. I have in mind especially the coal in a portion of a coal mine in the very territory that Mr. Campbell speaks of, Central Pennsylvania, a lower measure coal, in which the objectionable ingredients, both sulphur and ash are so inter-mingled with coal that the specific gravity of a great deal of the coal is in what we might call the twilight zone, preventing the economical separation into good coal and refuse by any of the known commercial methods of separation. Tests on this particular coal have been made by air flotation, by washing tests and by practically every other commercial means without any satisfactory results.

J. R. CAMPBELL. You refer to the Freeport coal?

W. L. AFFELDER. No, not to the Freeport coal, but to one of the Kittannings.

A MEMBER. Have you tried oil flotation?

W. L. AFFELDER. No, we have not, because the specific gravity tests of this coal show that practically no method of separation is going to be feasible; in other words, there is too gradual a gradation, between the specific gravity of the refuse and of the coal.

FRANK M. GENTRY.* First of all I wish to congratulate Prof. White on his very interesting and informative paper. This paper has a direct interest to me, for some time ago, altogether unaware of Prof. White's researches or of the experiments of Newall and Sinnatt, their valuable paper for some reason having been overlooked in a search of the literature, I undertook a theoretical investigation on carbonizing small par-

*Assistant to the Consulting Engineer, The New York Edison Co. (Submited in writing after close of meeting.)

ticles of coal in a radiant heat retort. A study of the combustion of pulverized coal in boiler furnaces furnished me with the clue to what I believed at that time to be a new principle of low temperature carbonization.

Rosin in Germany had made quite a theoretical investigation on the firing of pulverized brown coal. He pointed out that the pulverized coal could not ignite in the combustion chamber until it had absorbed sufficient radiant heat from the surroundings and that a flame of burning volatile matter distilled from the coal appeared before the coked particle combusted. He pointed out further that the absorption of heat by pulverized coal was so tremendous and rapid that indeed care had to be taken not to fire the coal too suddenly to prevent quenching the fire.

A little consideration showed that the radiant heat transferred between two bodies varied directly as the difference in the fourth power of the absolute temperature of the hot and cold bodies, directly as the area of the absorbing body and directly as a black body coefficient. Moreover, it could be shown mathematically that for a cylinder sufficiently long to render the end effect negligible, the inside surface was a perfect black body, that is, a perfect radiator of heat. The only coefficient entering into the transfer of radiant heat, therefore, in such a case is the black body coefficient of the cold body, in this case particles of coal. It so happens that coal has a pretty high coefficient and this coefficient probably becomes considerably greater when a certain amount of coking has taken place to reduce the particles' surface glaze. In addition, we know that radiant heat has the velocity of light and that within a cylindrical radiator, the amount of heat absorbed by a given area is independent of the distance.

Prof. White said that he had been unable to submit the problem to mathematical analysis. A series of theoretical equations have been set up taking into consideration various phenomena entering into the problem. Of course, simplifying assumptions must be made, but if elementary cases are solved, more involved cases can be studied. The equation, I am sorry to say, turns out in a form incapable of direct solution. Resort must be had to graphical methods and the points for two families of curves must be computed by the laborious method of ascertaining equation roots by trial and error. The work has not been completed but I hope that it will throw light upon a very important question. I am not prepared at this time to further discuss this particular phase of the subject.

Someone has asked Prof. White, in view of the temperature used in his retort, if this was a high or low temperature process. If you will turn to my discussion of General Patart's paper on the industrial transformation of bituminous coal into organic technical products you will see that I, among others, advocate the definition of low temperature carbonization from its products rather than its temperature. Low

temperature carbonization should be defined as distillation at temperatures which yield primary carbonization products. The temperature depends upon the physical conditions surrounding carbonization. Prof. White did not collect and examine his tar. By this definition, a gas analysis and a tar analysis would give a means of classifying the process.

I do not think Prof. White gave an ultimate analysis of the coals which he tested, but from what I know of Illinois coals, they probably contained a high percentage of oxygen. I think it has been pretty well established that high oxygen coals are very exothermic as compared with other coals heated under the same conditions. The fact that high oxygen coals yield a gas with high carbon dioxide content shows that at least some of the oxygen has been split from its original compounds to unite with carbon, thus liberating a large amount of heat, the remaining oxygen yielding mostly tar acids. Consequently, it looks as if this liberated heat might play an important part in this type of coal. This opinion is substantiated by the work of Prof. Parr who has developed a process for coking Illinois coal, depending largely on the exothermic reactions to heat the charge internally.

UTILIZATION OF COAL TAR PRODUCTS

By S. R. Church
Consulting Engineer, New York

Introductory

It is impossible to do more than attempt to sketch the subject of "Utilization of Coal Tar Products" in a paper of the desired length.

I shall deal with the outlets in which tar products find their technical uses, showing the wide and varied fields into which the coal tar

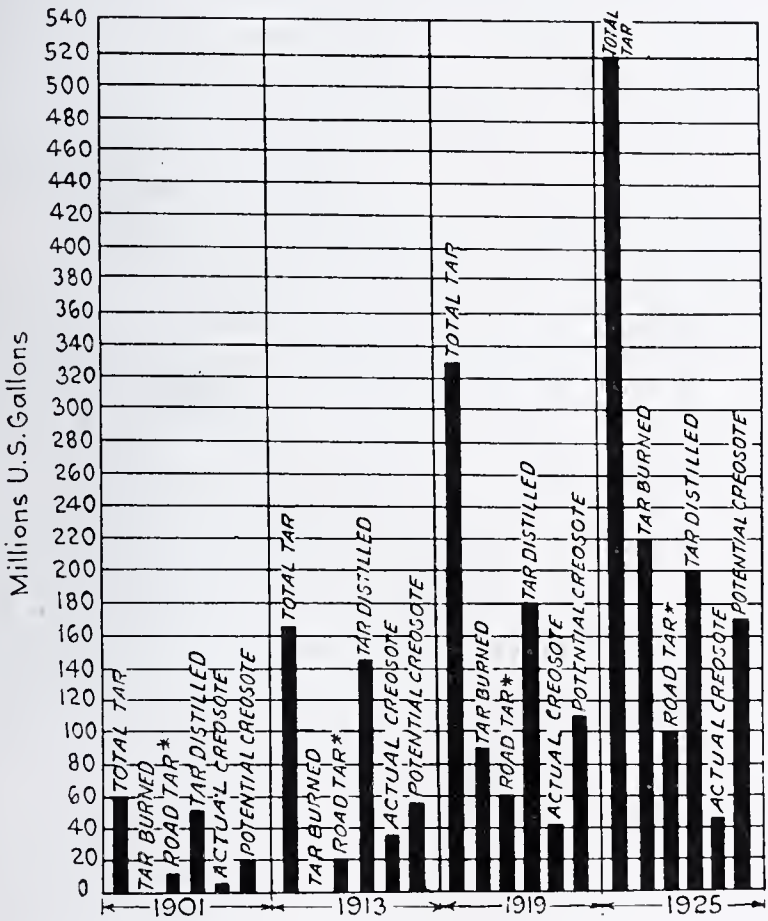

Fig. 1. Production of Coal Tar in the United States

*Road tar includes other uses of crude or dehydrated tar such as paints, pipe coatings, etc.

derivatives enter, and indicating the relative importance of these outlets from the standpoint of future development.

Another speaker has touched on the statistics of tar production during the period 1913 to date. Without repeating these data, I shall begin by showing in graphic form the production and principal disposal for coal tar in the United States in the years 1901-1913-1919-1925.

Those who desire to obtain a comprehensive picture of the situation in coal tar and other coke oven by-products ten years ago, for comparison with today, should read again the address of W. H. Childs in the Proceedings of the American Iron and Steel Institute, 1916.

The characteristic qualities of tars from various sources, and their bearing on utilization of tar products, can hardly receive more than scant notice. As to coke oven tars, the improvement in design and construction of ovens has resulted in increasing tar yields. (According to the U. S. Bureau of Mines the average yield per ton of coal on all ovens was 7.1 gals. in 1915, and 8.6 gals. in 1924). There has been a corresponding alteration in the tar. This is indicated by a comparison of coke oven tars from 26 plants in 1912.* and 29 tars in 1923, from the author's own notes. The average free carbon content was 8.61% in 1912, and 7.06% in 1923. The real difference is greater than this, as the tar burned is principally made on newer plants.

This gradual trend towards coke oven tars of lower free carbon content, together with a corresponding trend in gas works tars, due to the increased use of vertical retorts, is not altogether favorable from the tar utilization standpoint. Low carbon tars usually yield more oil and less pitch when distilled and this is generally desirable. On the other hand, for many uses, including road binders, roofing and water proofing pitches and numerous other purposes, specifications require a certain minimum of free carbon, and it is become increasingly difficult to obtain enough "high carbon tars" to meet these requirements.

Without going any more deeply into this phase of the subject, it may be said that in some sections of the country the tar now most eagerly sought for by tar distillers is horizontal gas retort tar

*Hubbard Coke-oven Tars of the U. S., Off. Public Rds. Circ. 97.

of fairly high carbon content, to make up the deficient carbon in the large proportion of their supplies.

Leaving this brief survey of tar production and quality, the subject of utilization will be rapidly outlined, taking up each of nine or ten industrial fields or outlets as separate divisions of the subject, in the hope that we may arrive at a point where some basis may be found upon which to consider reasonably the future disposal of the large volume of undistilled tars.

1. ORGANIC CHEMICALS

The importance of this outlet for coal tar products is usually over-estimated by those outside the industry. The proportion of coal tar which is represented by all of the volume of products in this group is less than 3%, based on the total tar distilled, or 1% of the tar produced. The largest item in the group, naphthalene, is a commodity on which the profit is generally quite poor.

In this field, as raw materials for oxidation, nitration, chlorination or sulfonation in the manufacture of intermediates for dyes, drugs, phenol-formaldehyde, resins, etc., tar products invite little attention in a review of this nature, as American practice is similar to European practice; and coal tar products have no competition from products otherwise obtained. The quality of the best grades of benzol, phenol and naphthalene produced in the United States is considered equal to that of European products. The demand for phenol and cresols has become so great, due to their extensive use in products of the Bakelite type, that large quantities of phenol are made by synthesis from benzol, and there is a shortage of cresylic acid. A major problem for research in this field is to find a process for synthesizing phenol at about one-half its present cost. The solution of this problem would result in an enormous increase in the production of phenolic resins.

2. PAINTS, VARNISHES, PRINTING INKS

This is a very minor field. The recent extensive development in nitro-cellulose lacquers has caused a larger demand for toluol and xylol.

There is the possibility of developing an outlet for the coumarone and indene resins in varnish making. These resins are obtained

from the solvent and heavy naphtha fraction of coke oven light oil, by polymerization. The potential supply is large and warrants further development. Shingle stains, printing inks, anti-fouling paints and various special types of paints and varnishes contain benzol or higher boiling coal tar solvents.

3. Drugs and Disinfectants

Although new disinfectants from various sources are constantly appearing, the use of coal tar disinfectants of the emulsion type steadily increases. The advent of new types of tar, rich in tar acids, opens an attractive line for research in this field, to determine whether the tar acids from low temperatures, especially the higher boiling fractions of these tar acids, may not be particularly desirable for the production of disinfectants having high bactericidal power and low toxicity to animal tissues.

Tar oils of specified tar acid content, naturally or artificially chilled to remove naphthalene, are used to a considerable extent as cattle dips.

4. Protective Coatings

In this and the succeeding groups the development of the utilization of tar products in the United States has followed more independent lines, and has been less influenced by European custom than in the case of the three preceding groups.

Also, in most of the succeeding uses, unlike those heretofore described, the American tar industry has had to compete with petroleum products. Hence it is in these fields that most ingenuity has been expended and our most important developments have been made.

One of the earliest uses of tar was for coating cast iron pipe, especially pipe used for water mains. Very little has been done in the way of research on coatings for cast iron pipe, and the old "Angus Smith Coating" formula which originated in England many years ago still finds its way into specifications. However, a large and representative sectional committee representing the manufacturers and users of cast iron pipe, is now engaged on the problems of standardization of pipe, studies of metallurgical problems, corrosion and coatings. In connection with the coating problem, sections of cast iron pipe are now under observation which have

recently been removed from service in New York after more than 60 years. A tar coated water main is in practically perfect condition with no accumulation of oxide on the interior. Another main of the same age, without coating, is choked to the extent of two-thirds of its capacity by products of corrosion.

For protection of steel and wrought iron pipes, asphalt coatings are usually preferred to tar, since they are not so susceptible to temperature changes and shock during shipping and storage. Many thousand barrels of tar and asphalt are used yearly in the manufacture of black "paints," for protecting metal and wood—and for coating old roofs. For the latter purpose, asbestos fibre is usually added to the tar.

While there is considerable difference of opinion, it is generally held that for paints, coatings, etc., tar offers better resistance to chemical attack, while asphalt has better physical properties. The increasing use of large diameter steel pipe for important water supply mains and other purposes offers opportunity for developing methods and materials for coating, which are now far from perfect. The Bureau of Standards about five years ago started an extensive series of field tests to determine action of soils of various types on coated and uncoated steel, alloys of steel and other metals. The results of these exposure tests are now being systematically observed and reported. This undertaking, together with the work of the Cast Iron Pipe Committee heretofore mentioned, will undoubtedly stimulate and educate our use of bituminous materials in the important field of protecting metal pipes and tubing for use underground.

5. Roofing

For seventy years roofing has been one of the most important outlets for coal tar. It has been much more important in the United States than in Europe. Literally thousands of acres of built-up roofing, consisting of four or five layers of tarred felt with alternate layers of pitch, surfaced with gravel or slag, cover important mills, shops, stores, office buildings and dwellings in American cities.

This important use of coal tar products has been retarded, first by the changing design of buildings, in which flat roofs are not so extensively employed as in the past, and second by the keen competition with asphalt. In the roofing field, the enormous development of asphalt shingles and roll roofing for use on dwellings and cheaper kinds of

industrial buildings has also brought it into extensive use for built-up roofings, with little or no price advantage in favor of tar products.

It is of interest to note that, without the roofing business, the coal tar industry in its present magnitude could not possibly have been built up, since for years there was no other outlet for pitch comparable with the European outlet for pitch in fuel briquetting. This industry has never been successfully established here on a large scale.

The pitch business of Great Britain has amounted to as much as 800,000 tons a year, more than one-half of which was exported, and nearly all of which was used for making briquettes. The total pitch business in the United States, including the soft pitch used as road binder, roofing, carbon pitch and all other outlets has seldom exceeded 400,000 tons.

The pioneers of the coal tar industry, whose properties were later combined to form what is now the largest tar distilling company in the United States, were all primarily roofing manufacturers; they distilled tar mainly to obtain roofing pitch; and made tarred felt, whose bases consist of low grade cotton rags, with paper and other fibres. The necessary distillates were in some plants regarded as nuisances, others more enterprising or resourceful developed profitable outlets for the oils.

6. LAMP BLACK—*Carbons*

The use of coal tar oils for lamp black continues, and these oils are generally preferred to petroleum oils. Water gas tar oils are also extensively used.

The aromatic hydrocarbons give higher yields than those of the paraffin series. Some black makers prefer oil containing naphthalene within specified limits. The substitution of carbon black from natural gas for many of the most important uses prevents advance in lamp black production.

The makers of electric carbons are important users of coal tar products. Tar oils, refined tar and several grades of pitch are used as raw materials in this industry. The most important demand is for a hard pitch, which constitutes about 25% of furnace carbons, the balance being largely petroleum coke. This is one outlet for coal tar pitch where petroleum residues cannot be substituted. Pitch has to be ground and petroleum asphalts are not "dry" enough to permit grinding. Fur-

ther, as compared with pitch, asphalt is deficient in fixed carbon, which forms the binder when the electrodes are baked.

Coke from coal tar pitch, if produced in large quantities, can compete with petroleum coke in this field. Pitch coke, on account of its relatively high purity, appears to have possibilities in the manufacture of absorptive carbon for industrial uses.

7. Metallurgical

Finely pulverized coal tar pitch is used quite extensively in the manufacture of compounds for foundry cores and facings. Tar is used in forming linings for basic steel furnaces.

Mr. Weiss has described the use of pitch coke in cupolas in making iron castings. This coke is to be distinguished from ordinary still coke, which has no metallurgical properties. The beehive oven pitch coke is exceedingly hard, difficult to ignite, and produces intense furnace heat.

This is the purest known coke, its fixed carbon on proximate analysis running 98.5% to 99%. Its use in metallurgy will probably be extended into the non-ferrous field, important investigations having already been made of its utility for direct melting of yellow metal scrap.

8. Miscellaneous

The varied minor uses for tar products range over such a wide field as to defy classification—for instance, tar is used to coat seed corn to prevent crows from picking it up; to preserve fishing nets, and to repel the advance of the army worm. Pitch is used to make flying targets for marksmen, to impregnate fibre tubes for electrical and chemical conduits and to hold glass lenses for grinding. Naphthalene mixed with cinders is used in the Pacific Northwest to prevent the ravages of the cabbage worm, and mixed with sulphur to combat the red spider in the West Indies.

Recent developments in sundry lines include:

The use of tar oils of high tar acid content in ore flotation. This has been curtailed by the substitution of chemical re-agents; many of these are coal tar intermediates.

Use of tar pitches and tar oils in mechanical rubber compounds. Asphalts, under the term "Mineral Rubber" has been widely used; tar products are rather difficult to introduce, but possess certain advantages.

Saturation or coating of fabrics for various purposes, such as conveyor belts, brake linings, etc.

9. Roadways

Extensive use of tar for road construction and maintenance has already been indicated. Although extensive, the use of tar for the purpose in the United States is by no means intensive, as compared with England, where about the same amount of tar is used annually on a territory one-sixtieth the size. However, it must be said that practically all of the tar used on roads in the United States is in the territory lying east of the Mississippi. We have developed along entirely different lines than in Europe, and especially in England where there are several hundred small plants producing road tars, many of them owned and operated by gas companies. The nearest approach to that situation exists in Boston and its metropolitan area. Here a number of companies are actively competing; in many districts in this territory tarred roads are the prevailing type. Generally, throughout the country, the distribution of road tar is in the hands of a few large companies operating service stations, tank cars, automobile tank wagons for spraying tar under pressure, and who maintain large corps of field men; all of which constitutes a highly organized and not extremely profitable business under present competitive conditions. The subject is so wide and so peculiar to itself that it cannot be fully reported here. It may be said that competition between tar and petroleum products is nowhere more keen than in this field. The latter are generally cheaper and are preferred for the construction of bituminous concrete. On the other hand, for cold surfacing, for maintaining existing surfaces, tar is preferred by many engineers. The trend in this field is not at present towards largely increased use of tar; the extent of the future demand for tar will depend on future supplies and prices of petroleum products.

10. Wood Preservation

No other important product of coal tar has enjoyed such a continuous and consistent expansion in its use over a long period of years as that of coal tar creosote for preserving wood. From 15 million gallons in 1905 to 108 million in 1913, only the cutting off of European oil during the war could retard this amazing progress.

It was not until 1923 that creoste again came in large volumes from Europe. Our total use reached 127 million* in that year and 167 million* in 1925. Of this, we have already seen that only one-fourth is produced in the United States. It is probable that the United States at present is consuming nearly one-half of the entire world production of creosote.

The principal use of wood preservatives is for railroad crossties. This constitutes, by volume, about 70% of the total wood treated. In 1925 about 50 million ties were treated with creosote or mixtures of creosote and other oils, and 14 million with zinc chloride. Another 50 million ties were used without treatment.

Creosote and zinc chloride are the only preservatives widely used, and the use of zinc chloride is not increasing. Leaders in the wood preserving industry agree that if an unlimited amount of creosote were available, its use could be greatly extended. In other words, the limit of railroad demand is not reached, and other uses, such as construction timber, poles for telegraph and telephone lines, highway bridges and fences, are limited by the supply.

The foreign creosote supply available for import to the United States can hardly increase in proportion to this country's potential demand. On the other hand, the question of price will play an important role in influencing our increased use.

The supply of creosote has been augmented by using filtered or carefully selected coal tar of low free carbon content. The combination, known as creosote-coal tar solution, usually contains 20% to 30% of tar. This has been used since 1908; and at present about one-half of the creosote-treated ties are treated with this solution. Service records over fifteen to sixteen years on several roads indicate a favorable comparison between solution-treated ties and straight creosote. The former appear to be equally well preserved, with somewhat less tendency to check.

Water gas tar creosote, and mixtures of this with tar, are being used to the extent of 4 to 5 million gallons a year, with apparently good results.

Several large railroads have during the past two or three years adopted the use of a mixture of creosote and petroleum. No standards

*Including tar mixed with creosote and water gas tar oils amounting in all to about 40 million gallons.

have been worked out for this practice either as regards the quality or quantity of petroleum to be used, nor has the industry as a whole accepted the merit of this practice, but at least it constitutes one of the factors that will lend to stabilize the creosote market.

Low temperature tars and oils distilled from these tars will be investigated with respect to their possible value in wood preservation. It should be understood that no tar which can properly be designated by the term "low temperature" will yield products that satisfy any of the existing creosote specifications. Nor will it be an easy matter, or a matter quickly dispatched, to convince the buyer of treated wood of the merits and lasting qualities of a new preservative. It is in the light of a new and untried material that these oils will be considered in the wood preserving field. Research on wood preservatives is being carried on by numerous agencies. The Forest Products Laboratory of Madison has a large department devoted to studies on the chemistry of wood preservation, and most of the published information is the result of this work. At least one large wood preserving company and two of the leading producers of preservatives have recently undertaken serious researches, one of them through the agency of the Mellon Institute. A large user of treated materials is reported to have perfected a series of inorganic preservatives which possess high value.

An accelerated test which will enable us to predict the comparative lasting value of new preservatives is much to be desired.

11. FUEL

Forty years ago this month the London section, Society of Chemical Industry, listened to a rather pessimistic address by Lewis T. Wright*, gas chemist and engineer of Nottingham, on the subject "What Shall We Do with Our Tar?" There was great depression in the tar products' business at that time, and burning was resorted to by many producers.

Wright said "It would surprise many people if they were told that tar only contains about 5% of substances having positive value as materials entering into chemical manipulation, and that the great bulk goes for common purposes, such as creosoting, lubrication and fuel.

"Surely the day will arrive when the great bulk, instead of select portion of the coal tar hydrocarbons, will have positive chemical uses,

*Jour. Soc. Chem. Ind. 1886, p. 563.

and who can doubt but that there are numerous triumphs yet to be gained by our chemists in that direction?"

After forty years the 5% limit still obtains; but tar burning is today more a matter of choice than necessity. In the United States coal tar has not been used as fuel on a large scale, excepting by the steel companies who produce it. Gas works coal tar has not been burned extensively, although many gas companies are using water gas tar as boiler fuel. The tar distillers have burned tar off and on, but not to an important degree. Pitch has been burned in liquid condition; at least one large tar plant has been running for several years on pitch fuel under boilers and stills, using pitch that is very hard at air temperatures and requires to be maintained at a temperature above 500° F. to the burners.

Pulverized pitch has been burned, at least on full works scale, but although this seems to possess many desirable qualities, pitch has not been available in most localities in large enough amounts at a competitive price that would justify the necessary equipment for burning as powdered fuel. Pitch, still coke, previously mentioned as a raw material for carbon electrodes, has also been used as domestic fuel.

The production of coke, either in stills, with recovery of distillates or in beehive type ovens, where the volatile is wasted, offers an outlet for tar with an assured disposal of the two major products, creosote and coke. It solves the problem of pitch disposal—but the value of creosote and coke as compared with the fuel value of tar in open hearth furnaces, etc., is an open question.

It is in the steel works, and especially in the Pittsburgh, Cleveland and Chicago districts, that the only important tar fuel problem resides. Within long range gun fire of this hall, tar is burned in steel furnaces, which if distilled to hard pitch or coke would more than double our domestic creosote production.

As Mr. Weiss has pointed out, this is almost wholly an economic question. The technical problems of finding a substitute fuel can certainly be solved, if it is profitable to do so. What the substitute fuel might be depends largely on locality and local practice. Powdered coal, mixtures of powdered coal and pitch, pitch alone, pitch mixed with fuel oil, and gas—alone or in combination with one of the foregoing—all seem within the range of possibilities.

If tar burning by steel companies continues at the present rate, the volume of tar available for distillation will nevertheless increase rapidly, I believe. It seems certain that out of all the interest in new methods of carbonization some plans will mature into large scale production. Apart from these projects the trend in the gas industry toward coal, and the awaking of that industry in every department of its activities, all point to more coal tar.

Tar utilization in the United States since 1900 has been in the hands of a few companies, the largest of these at one time handled about two-thirds of the total tar produced. The obvious advantages enjoyed by large companies are largely offset by the high cost of transporting tar. In a paper on "The Transportation of Petroleum,"* Charles Fitzgerald says that "the cost of moving crude oil in tank cars, especially over long hauls, is prohibitive, except for extremely high grade oil, under special conditions."

In my opinion, this will become true in regard to transporting crude coal tar. Large amounts of tar have been moved at a freight cost of more than one-half of the purchase price of the tar. Increased competition and elimination of uneconomic movements will result in more localized refining and utilization of coal tar.

In concluding, I want to venture the prediction that in all the larger outlets for tar products the future trend of uses and prices depends very largely on what is going to happen in the petroleum markets. If, as some petroleum technologists assert, the next ten years should see a virtual disappearance of low priced residuals, with a 75% conversion to gasoline, then obviously coal tar pitch could recapture a large volume of roofing, road binder and other business now lost in competition with asphalt. Assuming that no such radical change is likely to occur within so brief a period, there is every indication that the gradual trend is in that direction. This will mean a gradual rise in the value of all liquid fuels, until they reach a point where no such large scale burning of tar as is now conducted can any longer be justified. Perhaps that day may be not far distant.

*Amer. Inst. Mining and Met. Engineers, February, 1926.

COAL TAR DISPOSAL

By John Morris Weiss
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In presenting the subject of tar disposal to a conference such as this, where the attendance comprises a broad cross-section of those interested in the various phases of the industries based on bituminous coal, I felt it better to make my contribution mainly along the commercial lines of the subject rather than attempt to speak only of the purely technical phases of the matter.

When bituminous coal is distilled in gas retorts or coke ovens from eight to twelve gallons of tar are obtained per ton of coal carbonized, the amount and quality varying with the type of carbonizing unit, the conditions of carbonizing and the coal employed. The proper disposal of this by-product has a very distinct relation to the cost of gas in your homes and factories and of the steel used for construction purposes, since under today's market conditions there is an average credit value for the tar of at least five cents per 1000 cubic feet of manufactured coal gas, or, in the steel industry, sixty cents per ton of steel. Looking toward the future, low temperature carbonization systems, which have been discussed at such length in this conference, will produce from two to three times as much tar per ton of coal carbonized as in the older high temperature systems, and its disposal at a suitable price is one of the important points making for the commercial success or failure of the various systems proposed. Some of the promoters of low temperature systems are pronounced "optimists" (this description is decidedly charitable) in their estimates of the sales value of low temperature tar and only on the basis of extravagant values for tar and to a lesser degree for other products are they able to make their processes appear profitable on paper. The layman has in general an exaggerated idea of the value of tar, based largely on his knowledge that certain high priced dyes and medicinals are made from coal tar. He has not the slightest realization of the very small fraction of the total tar available for such purposes or the considerable labor and multiplicity of operations necessary for the conversion. His sense of values in relation to products such as gas and coke is considerably more accurate, and it is for this reason that the unscrupulous promoter, with the knowledge of human psychology that he must have, bolsters his esti-

mates by ascribing values to tar two or three times that of the maximum of the reasonably conservative chemical engineer.

In 1915 the total coal tar production of the United States amounted to about 180,000,000 gallons, of which 40,000,000 were from gas works (mostly horizontal retorts) and 140,000,000 from by-product coke ovens. By 1925 the gas retort tar had only increased to about 50,000,000 gallons, while the by-product coke oven tar amounted to about 470,000,000 gallons. The entire tendency in new high temperature carbonization is toward coke ovens and away from gas retorts. Apart from the above, the gas works also produce about 100,000,000 gallons yearly of carburetted water gas and oil gas tar, both resulting from the pyrogenetic decomposition of petroleum oils used for the production of gas. The production of carburetted water gas and oil gas tars is today just about the same as in 1918, and the tendency of the production is to decrease. The great bulk of the gas works tar is distilled, while somewhat less than half of the coke oven tar is so treated, the remainder being burnt as fuel in the steel plants producing it.

This practice may seem to be an economic waste, and many take this viewpoint; but from the steel man's standpoint there is much to defend the practice — the tar fuel is available in their plants and is not subject to transportation and other difficulties, it is low in sulphur and produces a flame especially suited to the open hearth furnace, and finally, at the prices at which tar could be sold to distillers, there is little or no financial advantage above the fuel value.

There is, however, some evidence of a change of attitude on the part of the steel mills, and more than passing consideration has been given in some cases to the question of the partial distillation or topping of the tar, separating light oils, phenol and cresols, and using the residue for fuel, while one mill has gone further and has actually installed a plant to distil their tar, separating creosote oil as well as light oil, and mixing the residual pitch back in emulsion with petroleum fuel oil to supply the liquid fuel necessary for their steel operations. This plant has been in operation only a short time, and information as to the commercial success of the plan is not available.

The great bulk of the tar not used as fuel is submitted to distillation—the distilling being handled largely by independent tar distillers. Besides the steel works previously mentioned, there are one large and several small gas works distilling their own tar. These gas works have been distilling for many years, apparently with satisfactory commercial results. The

question of the advisability of a producer distilling his own tar as compared with selling it to tar distillers is a decidedly open one. The producer has one great factor in his favor, viz., assurance of an uninterrupted supply of raw material which is essential to justify the capital investment necessary. A second essential is that the quality of tar be such as to make it suitable for the production of those residuals which have a ready sale in the available markets. Some tars are more fitted for the production of road materials, others for roofing pitch, etc. and some are rather unsuited to good quality residuals for any of the usual purposes without blending with other type tars from different sources. In general, there is no difficulty in marketing the distillates from high temperature tars in the wood preserving field. Even today less than half the creosote oil used in the United States is of domestic origin, the balance being imported, largely from England and Germany. The residual question, "the burden of pitch," however, has been the stumbling block in many commercial tar distilling projects, and eliminating the possibility of unsalable pitch is certainly necessary for success.

The production of tar must also be of a quantity to make operations profitable; but this varies so with geographical location that generalization as to this point is impossible. Every such project requires careful study with especial reference to the tar or tars to be handled before the advisability and probable returns from the venture can be estimatd. In some cases very little above the ordinary sales price of the tar can be expected to accrue, certainly not enough to warrant the investment required, while in other cases, the nature of the tar in question and the situation regarding markets and pitch disposal are such that a very handsome profit can be obtained.

Technical development in the tar industry of the United States has been rapid in the last ten or fifteen years, especially in the field of refined products and their derivatives. The use of residuals as road materials has also undergone a tremendous development, and better knowledge of these products, combined with intelligent sales effort has multiplied the market in this field many times until today road materials production is by far the largest single use of residual tar products. In the present paper, however, the writer will confine his technical discussion to two main topics: first, the improvements in tar distilling methods, and second, the means by which the "burden of pitch" has been lightened and probably eliminated for all time as an important factor in the industry.

Tar distillation in the United States some fifteen years ago was

entirely carried on in horizontal batch stills using a slow current of air for agitation during distillation. Yields of oil from coke oven tar to a 300° F. melting point fuel pitch averaged about 40% by volume of the tar distilled. A study of the fundamentals of tar distillation, with which the writer was intimately connected, brought to light the facts that the distillation of tar involved a chemical cracking reaction, taking place in the neighborhood of 300° C. (700° F.), giving rise to some permanent gas, increasing the matter insoluble in benzol ("free carbon") and increasing the pitch of a given melting point obtained at the expense of oil yield. The action was accelerated decidedly by the oxygen in the air ordinarily used for agitation. The cracking reaction increases both with time of heating and temperature, and the ideal tar distillation system would therefore be one which exposes the tar to the lowest temperature for the shortest possible time necessary to produce the desired residuals. The lowering of temperature can be obtained by the use of vacuum on the stills, and this was adopted in several plants in 1912. It resulted in materially better yields of oil (about 10% at a 300° F. pitch) but is limited in batch stills to this degree of hardness, as above this point cracking and gas evolution render it impractical to maintain the vacuum necessary for the continuance of the distillation. Moreover, ordinary batch stills require considerable strengthening to resist the high vacuum required to produce results. With these disadvantages in mind the writer developed a system entirely free from these difficulties, which has been described in his U. S. Patent No. 1,418,893, issued June 6, 1922. This involves the recirculation of an inert gas such as carbon dioxide or nitrogen in amount sufficient to give a decided vapor pressure lowering to the distillate oils. The process can be readily adapted to regular batch tar stills without structural changes, as it merely involves the addition of a gas circulating pump, closed oil receivers and some additional piping. In practice no provision for inert gas is necessary, as the system may be started filled with air, the oxygen is rapidly absorbed and the recirculated gases become substantially nitrogen. The influence on oil yield may be indicated by taking results on a coke oven tar of 8.5% free carbon distilled to 280° F. pitch. The ordinary method of the batch still gave 40% by weight of distillate, while the recirculation method gave 53% by weight of oil to the same point. The commercial advantage is very considerable when the difference in value of oil and pitch of about seven cents per gallon is considered. The increase means about one cent more per gallon of tar in the value of products obtained. The recirculation method has an added advantage

in that the distillation can be carried to a much harder pitch without danger of coking. Before this method was evolved 300° F. melting point was about the limit, while with recirculation pitches of 400° to 450° F. melting point were readily obtained, naturally with a further increased distillate yield. The ability to make these harder pitches has been of great advantage in pitch coke manufacture and in the obviation of the burden of pitch. The recirculation method has been and is still operated as standard practice in at least two plants with very satisfactory results.

Along the lines of reducing the time of distillation certain batch stills have been equipped with internal flues to increase heating surface, and thereby speed the operation; but this practice is decidedly inferior to the recirculation method. Better results have been obtained with continuous tube stills when the volume of tar handled at a given point was sufficient to justify the operation. The stills of this type in operation in the United States have given quite satisfactory results. The tar is pumped through a heated coil under pressure, and the heated liquid tar is discharged into a vapor box where the oil vapors and pitch separate. As developed, they are single stage when operating on pitches up to 200° F. melting point, and double stage when running to 300° F. pitch, which is about as hard as has been made in this type of apparatus. The raw tar undehydrated is usually first introduced as cooling means in the various oil condensers. By these passages it is heated sufficiently so that when discharged into a vapor box the water and light oils are volatilized, and the dry tar pumped to the first coil in a furnace heated by liquid pitch fuel. After passing the coil the tar is sprayed into another vapor box where vapors are taken off to fractional condensing means, and the residual intermediate pitch pumped to a second coil in a hotter zone in the furnace and the process repeated. The final pitch discharges to coolers or bays, or preferably to a mechanical cooling and disintegrating machine which delivers hard pitch in comminuted form suitable for loading and shipment.

The successful conduct of such stills requires great care in the design and proportion of parts, relation of heating surfaces, condenser surfaces, velocities, etc., so as to obtain a balanced installation of high thermal efficiency. The stills are remarkably flexible, making pitches from 100° F. to 300° F. in melting point and changing from one grade to another without interruption of operation. The smallest still of this type in use handles from 30,000 gallons to 50,000 gallons of tar per 24 hours, depending on the tar charged and the pitch desired, while one unit (the largest in operation) has a capacity of from 90,000 to 140,000 gallons of tar per 24 hours.

Oil yields in these stills run from 10% to 15% better at 300° F. pitch than in the ordinary batch stills, and this is due to a reduction of the time of heating to less than one-fifteenth of that required in batch still operation. The final temperature in tube stills is higher than in batch stills, but the time at these temperatures is very short.

Oil yields in the present tube stills can be further improved and harder pitches made. In a series of semi-works tests, carried on under the direction of the writer, it was found possible to take a coke oven tar of 7% free carbon content and obtain 82% by volume of distillate, with a liquid pitch residue of 500° F. melting point and 60% free carbon. There is no doubt that if desired these results could be approximated in practice.

The question of proper oil fractions in connection with tube stills has also received considerable attention. The tube stills showed lower labor costs, lower fuel costs and an all-over cost of 50–75% of the batch still costs. The fractions obtained were, however, inferior. By the development of continuous fractional condensing columns this single disadvantage was obviated and better cuts were obtained than with batch stills—if anything, closer boiling than the industrial needs demanded. It is possible and practical to separate a reasonable number of close cut fractions by the use of a properly designed and constructed condensing column. Each column must be designed with reference to the use to which the oils are to be put. If the bulk of the middle oils is to be sold in mixture with the heavy oils as a wood preservative, a very simple installation suffices; if, however, a separation is to be made into an acid oil, a naphthalene oil, a heavy oil and an anthracene oil, an entirely different type of design is required.

The developments in the distillation of tar have contributed in no small measure to the value of tar. At present oil market prices the extra value obtained by proper and efficient methods of distillation may amount to as much as two cents per gallon of tar as compared with the methods in use some ten or fifteen years ago.

The one bugaboo of the tar industry in the past has been the disposal of pitch. Oil could always be moved at a price, but not so the residuals. Most of the uses of coal tar pitches are highly competitive with petroleum bitumens and native bituminous materials, and at times pitch could not be sold at any price at all, but was simply piled up in bays with the hope that some disposal might be found. At one time in the history of the industry there were literally acres of pitch at one plant with surplus stocks all over the country, and the question of storage space was an acute prob-

lem. Naturally, considerable effort was expended on the problem, and pitch coke at last proved to be the solution. The story of various unsuccessful attempts is too long to even abstract here. Finally the discard of the coal coking industry, the beehive oven, was found to be the best adapted type of equipment, and in the last five years over 300,000 tons of pitch have been handled in this way. The pitch used is very hard, having been submitted to the recirculation distillation method of the writer, thereby extracting all salable distillate before the coking operation.

The coke produced is of unusually high mechanical strength, and because of this and its freedom from ash and sulphur was found especially useful in some special phases of the metallurgical industry, for example, in the production of delicate or high grade castings. Beehive pitch coke has commanded a very substantial premium over the best grades of coal coke, the sales price being at times about double. The market for pitch coke too is decidedly unsaturated. The successful coking of pitch has provided the necessary outlet for surplus stocks of tar where the residuals cannot be marketed in the regular channels. There is a broad open market for the distillates in the form of creosote oil, as more than half of the creosote oil used here is imported, and if necessary the treating of wood could be stimulated. The coke outlet forms a balance wheel allowing the working up of expanding supplies of tar without piling up large tonnages of unsalable pitch, as was the situation of the industry prior to 1919.

The future disposal of tars from the low temperature distillation of coal presents a variety of problems. There is considerably more variation in the quality of low temperature tars among themselves than is the case with high temperature tars. With the temperatures employed in the gas retorts and in the by-product coke oven cracking goes on to such an extent that all the products, regardless of source, reduce to a certain general level in which there is of course a variation, but one of degree rather than of kind. All the oils from high temperature tars fall into a range of specific gravity in relation to boiling point, so as to admit them under the wood preserving specifications. All the high temperature tars contain tar acids, but rarely over 3% of the tar, and so on.

When we turn to low temperature tars we find very much sharper differences between individuals within the class. Since low temperature carbonization involves much less cracking and decomposition of the oils the raw material used—that is, the type of coal—exerts a far greater influence on the type of product. Add to this variations in apparatus, temperature of carbonization, time and similar factors, and the variations be-

come even more striking. The writer has seen variations in tars of low temperature origin of a magnitude such as 10% of tar acids based on the tar in one case and over 40% in another. Similarly one tar may give only 40% by volume distillate to a 300° F. pitch, while another will yield over 80% to the same point. Chemically and physically two low temperature tars may be of an entirely different breed and absolutely different in their commercial possibilities. In any estimation of the value of a tar from a low temperature carbonization system too much emphasis cannot be placed on the necessity of a careful assay of the tar instead of dealing in generalities, as is so often the case.

The question of the disposal of products from low temperature tar is by no means solved. A moderate amount can be disposed of in the older channels, but any very large production coming suddenly on the market would only find immediate disposal as a liquid fuel. In general, although some exceptions have been noted, the oils from low temperature tars are of too low gravity to meet the present wood preserving oil specifications. This does not mean that they are not efficient wood preservatives, but does mean that they must be demonstrated and specifications which they will meet approved. Work to this end has been started in several quarters, but is necessarily slow. Water gas tar products were pushed for over ten years before they attained their first real recognition for wood preserving purposes, and low temperature tars will have to take the same course, except that a greater speed can be obtained due to the advance of technical methods in evaluating materials. The same obstacles exist in all the various fields of use of the residuals, and it will require investigations to determine the limits of usefulness and to demonstrate to the consumers these limits before extended sales can be expected. At the same time it must be realized that there are outlets for low temperature tar and its products in other fields than those occupied by high temperature tar, due to their own peculiar properties not shared by high temperature tar. The writer believes that as high or higher values can be obtained from low temperature tars as from high temperature tars, but realizes that to do this requires a great deal of effort and hard work, just as has been required by the development of values from the older tar products. Those entering the field of exploitation of low temperature tars on a large scale must, to be conservative, place the tar value at that of liquid fuel and then build and diversify from this basis into fields of greater return.

THE RECOVERY OF PHENOLS FROM STEEL PLANT FUEL TARS

By Robert M. Crawford
Chemical Engineer

Recent estimates give the annual production of coal tar in the United States at about 550,000,000 gallons, of which about 60%, or 330,000,000 gallons is burned as industrial fuel and the balance, about 220,000,000 gallons, is distilled. The steel industry, which is of course the largest producer and consumer of coal tar in this country, has good and logical reasons for using tar as fuel—it is a convenient, cheap and dependable source of fuel; it is claimed that better steel melts can be had with tar than with fuel oil, and other less obvious reasons contribute to the burning of tar by the steel industry. Of the 220,000,000 gallons of tar distilled in this country only a small fraction is distilled into products yielding oils from which tar acids can be extracted for subsequent refining. The difficulties of marketing the pitch residues contribute to the inability of the tar distillation industry to supply this country's needs, among other things, for phenol and cresols which exist naturally in the free state in most tars.

The present estimated annual consumption of phenol is about 15,000,000 pounds, of which approximately 12,000,000 pounds are produced synthetically, while only 3,000,000 pounds (20%) are supplied from the natural coal tar source. There is being burned annually about 20,000,000 pounds of phenol in the combustion of coal tar fuel.

The present estimated annual consumption of cresylic acid and other grades of cresols is about 1,700,000 gallons, of which approximately 1,000,000 gallons are imported and the balance, 700,000 gallons (40%), is supplied from the coal tar distilled in this country. There is being burned annually about 3,000,000 gallons of cresols in the combustion of coal tar fuel.

The general situation outlined above does not appear to be economically sound when one considers that there are more tar acids destroyed in the combustion of coal tar than is needed to supply our demands for these products in the refined state. It appears certain that the present situation will become less desirable each year, considering the present

development of new uses for phenol and cresols and the increasing demands of our great American chemical development—the synthetic resin industry—which appears, it is said, to have but scratched the surface of its market and which depends upon adequate and cheap supplies of phenol and cresols as basic raw materials.

The recovery of phenols from coal tar fuel could easily and cheaply be accomplished without seriously affecting the fuel value of the tar, by distilling the raw tar to remove such oils which contain the main quantity of phenols; recovering the phenols from the oil; and cutting back the pitch from the distillation with the extracted oil. The resultant mixture of pitch and oil would be a dehydrated, acid free, tar for fuel purposes which would still contain 95% of the total available heat units in the raw tar. We would by such a procedure produce phenol and cresols in adequate quantities for domestic markets from the natural source of these products without seriously depressing the fuel value of the tar.

The following is typical of coke oven tar:

	Water	B.t.u./lb.	Sp. G.
Raw tar	1.5%	15,898	1.13
Raw tar .....dehydrated		16,132	1.14
Acid free fuel tar.....	None	16,244	1.14

The fuel tar above actually has a higher calorific value per pound than the raw tar because water has been removed, and after all corrections have been made for changes in volume we find that the fuel tar made from one gallon of raw tar still contains 95% of the original heat units in the raw tar. Not all tars in this country are adaptable to the above procedure as a commercial proposition; but several steel plant tars having the proper composition are being produced in sufficient quantity to fully justify the topping method proposed.

The method which the writer has in mind would be conducted as follows:

The raw tar would be distilled in a continuous tar still for the removal of all oils, boiling to a vapor temperature of say 250° C. The distillate would be separated from the ammonia liquor, which would be sent to the coke plant weak liquor system and the oil then stripped of phenols by continuous alkali extraction. The residual "neutral oil" would then be continuously mixed with the pitch from the tar still to generate the fuel tar which would be burned instead of the raw tar.

For the continuous extraction of the phenols from the oils a method devised for the purpose appears to be most suitable. The method makes use of extracting the oil in continuous counter-current fashion with a solution of sodium sulfide in such a manner that selective recovery of phenols and cresols can be had, producing a sodium phenolate which predominates in phenol and a sodium cresylate which predominates in cresols. An experimental plant has successfully demonstrated that the continuous selective recovery can be accomplished, and two commercial plants are now operating over the continuous extraction system without selective recovery.

Sodium sulfide is preferred as the alkali extraction medium, instead of sodium hydroxide which is commonly used, because by its use we can effect a regeneration of the sodium sulfide by the use of hydrogen sulfide as an acidifying agent to decompose the phenolates. This regenerative cycle can best be illustrated by the following equations:

(1) $2\ PhOH + 2\ Na_2S = 2\ PhONa + 2\ NaHS$

(2) $2\ PhONa + 2\ NaHS + H_2S = Na_2S + 2NaHS$

(3) $Na_2S + 2\ NaHS + \text{heat} = 2\ Na_2S + H_2S$

(4) $2\ PhOH + 2\ Na_2S = 2\ PhONa + 2\ NaHS$

(5) $2\ PhONa + 2\ NaHS + H_2S = Na_2S + 2\ NaHS$

etc.

Equation (1) shows the reaction of a phenol with sodium sulfide solution.

Equation (2) shows the liberation of the free phenol by acidifying the products of Equation (1) with H_2S gas.

Equation (3) shows the decomposition of the spent liquor product of Equation (2) regenerating the sodium sulfide and the H_2S gas.

Equation (4) is a repetition of Equation (1) using the regenerated sodium sulfide in Equation (3) to absorb additional phenol.

Equation (5) is a repetition of Equation (2) using the H_2S gas product of Equation (3) to liberate the phenol.

It is obvious that the above series of reactions is a double regenerative cycle which regenerates the sodium sulfide for phenol extraction as well as the H_2S gas for phenol liberation.

It is not possible, of course, to operate such a cyclic system commercially without losses—the mechanical losses must therefore be made up by the addition of small quantities of caustic soda and H_2S gas. The system has been operated on a semi-plant scale for some time at a re-

generative efficiency of 95%—that is on 5% made-up of caustic soda.

In order to present the commercial aspect of the proposed scheme for the recovery of phenols from steel plant fuel tars, the following estimate pertaining to a hypothetical case is given:

Assuming a steel works coke plant producing 70,000 gallons raw tar per day having the following characteristics:

Water	1.45% (by vol.)
Distillate to 250 C	15.0% (by vol.)
Tar Acids in Distillate	23.5% (by vol.)
Calorific value (crude)	15,898 B.T.U./#
Calorific value (treated)	16,244 B.T.U./#

There would be produced per day approximately:

Crude Phenol	800 gal.
Crude Cresylic Acid	1,650 "
Fuel Tar	65,000 "
Weak Ammonia Liquor	980 "
Loss (Tar)	1,570 "
Total	70,000 gal.

The recovery plant would cost approximately $225,000 installed and and the following is an estimate of annual operation costs:

ESTIMATE OF ANNUAL OPERATING EXPENSE

			Round Figures
(1)	*Materials:*		
	Distillation Loss (Tar):		
	1570x365—573,050 gal. @ 5¢	$28,650.00	
	Caustic Soda (5% Make-up):		
	400x365—146,000# @ 3¢	4,380.00	
	Hydrogen Sulfide (1% Make-up):		
	40x365—14,600# @ 25¢	3,650.00	
	Sulfuric Acid:		
	300x365—55 Tons @ $10.00	550.00	
	Tar Acids & Water Removed:		
	3430x365—1,252,000 gal. @ 5¢	62,600.00	
	Total	$99,830.00	$99,900.00/yr.
(2)	*Labor:*		
	3—Stillman @ $6.00/day	$ 6,570.00	
	3—Extractors @ $6.00/day	6,570.00	
	3—Helpers @ $5.00/day	5,475.00	
	1—Foreman @ $200/month	2,400.00	
	Total	$21,015.00	21,100.00/yr.

(3)	*Fuel:*		
	70 gal. tar/hour for Still		
	70x24x365—643,000 gal. @ 5¢	$32,160.00	32,200.00/yr.
(4)	*Supervision:*		
	Part time main Plant Superintendent	$ 1,000.00	
	Part time main Plant Chemist	1,000.00	
	Total	$ 2,000.00	2,000.00/yr.
(5)	*Power:*		
	500,000 KW @ 1.3¢	$ 6,500.00	6,500.00/yr.
(6)	*Steam:*		
	10,000 tons @ 50¢	$ 5,000.00	5,000.00/yr.
(7)	*Depreciation:*		
	10% on $225,000.00	$22,500.00	22,500.00/yr.
(8)	*Maintenance:*		
	5% on $225,000.00	$11,250.00	11,300.00/yr.
(9)	*Administration:*		12,000.00/yr.

SUMMARY

Materials	$ 99,900.00/yr.
Labor	21,100.00 "
Fuel	32,200.00 "
Supervision	2,000.00 "
Power	6,500.00 "
Steam	5,000.00 "
Depreciation	22,500.00 "
Maintenance	11,300.00 "
Administration	12,000.00 "
	$212,500.00 "

The revenues from the operation would be derived from the sale of the recovered phenols and credits for ammonia liquor recovered. We thus have annual credits as follows:

	Round Figures
Crude Phenol:	
800x365=292,00 gal. @ 50¢	$146,000.00
Crude Cresylic Acid:	
1,650x365=602,250 gal. @ 30¢	180,700.00
	$326,700.00

The above figures are believed to be conservative and show a net annual income of $114,200.00 or a return on the investment of about 51%.

Considering the proposed scheme from a fuel standpoint, the total heat in one gallon (9.5 lb./gal.) of the raw tar as now burned

is about 151,000 B.t.u., while the total heat in one gallon (9.5 lb. 1 gal.) of the processed tar is 154,300 B.t.u.; but since the total volume of the fuel tar is 93% of the volume of the raw tar the loss of heat due to the use of the process is but 5%. We have apparently shown that a steel plant producing its own tar for fuel can make a substantial contribution to domestic supplies of phenol and cresols without seriously depressing the fuel value of the tar and at the same time make an attractive return on the investment.

THE FORMATION OF NAPHTHALENE DURING HIGH TEMPERATURE CARBONIZATION

By Y. Kosaka and Y. Oshima

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The mechanism of naphthalene formation in coal tar is not yet clearly explained. It has been agreed by many authors that the low temperature tar contains neither naphthalene nor phenol, while high temperature tar does. It has also been observed that there is much more acid oil in low temperature tar than in high temperature tar. It may be quite natural to assume that naphthalene is formed by a thermal decomposition of cresols, xylenols and other higher phenols prevailing in low temperature tar.

According to Dr. Fischer and his colleagues, cresols are demethylated into phenol, which in turn are polymerised into naphthalene, giving off CO and hydrogen, or are reduced to toluene, depending on conditions.

1. $2C_6H_5OH$ ..... $C_{10}H_8+2CO+2H_2$
2. $C_6H_4CH_3OH+H_2$ ..... $C_6H_5CH_3+H_2O$

They also reported that naphthols and their derivatives are reduced just the same as the above and form naphthalene:

3. $C_{10}H_7OH+H_2$ ..... $C_{10}H_8+H_2O$

Some of alkyl naphthalenes in low temperature tar have already been found by several experimenters, but the existence of naphthols is not yet clearly reported. It may be found in the acid oil, but it does not seem that the amount approaches the large quantity of naphthalene found in high temperature tars.

In course of research work on the constitution of low temperature tar acid oil, we examined the cracked products formed under certain conditions and found that naphthalene is always formed from any fraction of it, and lately our work shows that it is formed even from benzene or phenol.

The experiments were carried out at 850°C. and in contact with coke, so that the decomposition would follow actual conditions in a

carbonization retort. It was found that higher phenols, the cresol fraction and pure phenol form benzene, naphthalene and anthracene. It was also observed that pure benzene and toluene polymerise into naphthalene and anthracene.

It is pretty well known that phenols form benzene and its homologue by dehydration, and we want to say, therefore, that it is phenols which produce most of naphthalene in coal tar. Phenolic vapor formed by low temperature carbonization of coal is decomposed at high temperature and in contact with coke layer into naphthalene, either through phenol or benzene and its homologue. Phenols are dehydrated by two ways, i.e., first by hydrogen giving water and second by carbon giving carbon monoxide. Cresol, for example, would react as follows:

4. $C_6H_4CH_3OH+H_2$ ..... $C_6H_5CH_3+H_2O$
5. $C_6H_4CH_3OH+C$ ..... $C_6H_5CH_3+CO$

The toluene is then polymerised into naphthalene. Naphthalene formation from toluene is accompanied by hydrogen, which will probably reduce toluene into benzene and methane, and also cresol into phenol and methane:

6. $C_6H_5CH_3+H_2$ ..... $C_6H_6+CH_4$
7. $C_6H_4CH_3OH+H_2$ ..... $C_6H_5OH+CH_4$

Then again benzene and phenol are decomposed into naphthalene.

A part of the cresols is changed first to toluene, then to benzene and naphthalene, while the other is demethylated into phenol which in turn is polymerised to naphthalene, as Dr. Fischer reported, giving off carbon monoxide and hydrogen. Hydrogen thus formed may serve also in dehydrating cresols and form toluene. Thus the formation of naphthalene takes place in three ways:

1. Decomposition of alkyl naphthalenes.
2. Decomposition of naphthols and their derivatives.
3. Decomposition of phenols.

The latter, we believe, is the one which predominates.

Experimental:

50 to 100 grams of sample were taken each time and dropped down into the reaction chamber which is fixed in a vertical furnace, heated electrically. The upper part of the furnace is kept at a temperature a little above boiling point of the sample so that the latter is quickly vaporized. Nearly two-thirds of the reaction tube is filled with metallurgical coke (10-20 mesh), and it is heated at constant

temperature of 850°C. throughout the experiment. The speed of dropping sample is about 5-6 hours for 100 grams, while the whole system is kept under pressure of —10mm. of water column. The coke is changed every time and the temperature of the reaction tube is set at the desired point when the suction is regulated and the sample is dropped in gradually, keeping the pressure in the system and the speed of charge constant.

The products of decomposition are brought out through a water cooler and then again through an ice-cooled condenser, while the gas volume is measured and the gas sample is taken every half hour. The condensate is collected and distilled in a normal Engler flask. For the sake of convenience the distillates were fractionated into five parts, namely, up to 110, 110 to 210, 210 to 270, 270 to 315, and 315 to 360°C. The results are summarized in the following table:

Sample	Higher Acids	Cresols	Phenol	Benzene	Toluene
Condensate.					
Yield %	21.2	48.3	56.9	88.3	56.1
Water	0.8	3.0	3.5	...	...
Up to 110	3.5	15.8	16.5	56.4	32.2
110-210	...	...	12.0	...	...
210-270	5.1	6.8	8.8	16.3	7.8
270-315	1.4	2.5	5.2	3.0	2.8
315-360	2.4	2.0	4.9	1.4	2.5
Residue and loss	8.7	11.4	9.7	12.8	10.8
Gas measured, 1/100 g.	95.0	42.0	35.0	15.0	33.0
Composition:					
CO_2	1.1	0.2	0.2	0.1	...
O_2	...	1.4	0.7	0.7	0.3
C_nH_m	3.6	3.6	2.9	2.9	2.9
CO	25.0	33.8	43.4	...	...
CH_4	29.1	21.6	11.4	8.2	40.7
H_2	35.4	30.9	35.2	81.3	55.5
N_2	5.8	8.5	6.8	6.9	0.9

It is to be noted that each fraction is very sharp and naphthalene comes out subliming in fine crystals. Anthracene and higher fractions are always slightly colored pale yellow or yellowish green, while residues are colored dark green.

If benzene is polymerised to naphthalene and anthracene, theoretical maximum yields are respectively 82 and 76 per cent. Taking the experimental results in regard to benzene, 56.4% remains undecomposed, and the amount of anthracene formed is 3% of the

sample, which corresponds to 4% of benzene. Therefore, if we assume that the residual benzene, 29.6%, is decomposed to naphthalene, its yield should have been 32.5% instead of 16.3% found. Again, about 12 liters of hydrogen are formed from 100 grams of benzene. If anthracene is formed according to

$$3C_6H_6 \text{ ..... } C_{14}H_{10}+4C+4H_2$$

3 grams of anthracene are accompanied by 1.5 liters of hydrogen. If we assume the remaining hydrogen, 10.5 liters, is made in accordance with the formation of naphthalene, the latter would be 30 grams, which is nearly the same as calculated above. If we take the experimental results of naphthalene formed, 16.3%, the amount of hydrogen is 5.7 liters and the rest of the hydrogen, that is 4.8 liters, should have been due to further decomposition of benzene leaving unknown solid products.

If toluene is decomposed to benzene and methane, 100 grams of it produce 17.4 grams or 24.5 liters of methane, while 13.4 liters are being found in the experiment. It means that 55% of toluene is decomposed to benzene. If we take the former result of naphthalene formation from benzene, 16.3%, then 8.3% of naphthalene should be formed from toluene, while 7.8% is the result of experiment.

Then again we can calculate the quantity of benzene to be formed according to

$$C_6H_5OH+H_2 \text{ ..... } C_6H_6+H_2O$$

Theoretically 19 grams of water are formed from 100 grams of phenol, while water found is 3.5 (1 gram of water was previously added to make phenol easily dropping, hence 4.5—1.0=3.5). That means 18.4%. If naphthalene is formed from phenol according to

$$2C_6H_5OH \text{ ..... } C_{10}H_8+2CO+2H_2$$

we can calculate the quantity of naphthalene from the volume of CO found. Theoretically 100 grams of phenol produce 30 grams or 24 liters of carbon monoxide, while 15.2 liters are found. That means 63%. The same will be said even when we assume the reaction

$$C_6H_5OH \text{ ..... } C_6H_6+CO$$

Therefore it may be said that 18.4 and 63.0 of phenol were decomposed into benzene and naphthalene, respectively, while 12.0% remained undecomposed and the rest decomposed further.

Lastly, in regard to cresol, it may be assumed the following two reactions take place:

1. $C_6H_4CH_3OH+H_2$ ..... $C_6H_5CH_3+H_2O$
2. $C_6H_4CH_3OH+C$ ..... $C_6H_5CH_3+CO$

Using the quantity of water and carbon monoxide found it may be easily calculated that 18% and 67% of cresol are decomposed according to the reaction 1 and 2 respectively. Here we assumed that cresols are decomposed to toluene in both cases, therefore 85% altogether went to toluene. Now if we take the figure attained by the cracking of toluene and apply it to the above case, 55% of it went to naphthalene, therefore 6.7 grams of naphthalene would have been formed from cresol while 6.8 grams were found.

It may be correct to state that phenols in low temperature tar are reduced to lower phenols under the conditions prevailing in the carbonization retort and also to hydrocarbons by means of carbon and hydrogen respectively. The formation of carbon monoxide in town gas is due not only to the reduction of carbon dioxide or water vapour, but also to the reaction between carbon and the vapour of phenols.

SUMMARY

1. Naphthalene formation by cracking benzene, toluene, phenol, cresol fraction of a low temperature tar and a higher phenol fraction of the same was studied.

2. The reaction between carbon and phenols was also studied.

3. A theory is proposed that some of naphthalene is formed through the decomposition of phenols formed during the early stages of the carbonization of coal.

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DISCUSSION

CHAS. M. A. STINE.* The chemistry of coal tar has been a rich and productive field for chemical research ever since W. H. Perkin's preparation of mauve in 1856 and Adolph Baeyer's snythesis of indigo in 1870. One has but to pick up a volume of Beilstein and compare the tremendous list of compounds that have been prepared from the coal tar intermediates with the comparatively small number of compounds which have been prepared from other hydrocarbons, to appreciate the

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tremendous stimulus which the commercial manufacture of dyes has given to the chemistry of coal tar intermediates. Not only dyes, but their derivatives such as lakes and, in very recent years, some highly important medicinal preparations and pharmaceuticals of various kinds have come from the laboratory of the coal tar chemist.

In connection with the chemistry of coal tars, the rubber manufacturer has had placed at his disposal compounds for the acceleration of the vulcanization of rubber which have made possible some very valuable developments in the rubber industry. The separation of ores and the concentration of the metalliferous content of these ores has depended upon the application of other types of coal tar derivatives. Even with all that has been done in the way of the development of the chemistry of coal tar derivatives, the growth and progress of the science produces almost from month to month new and highly valuable products from this source. New dyes, new pharmaceuticals, germicides and fungicides, the new and interesting compounds such as Semesan which are used for stimulating the germination of cereals and seeds of various types and preventing the growth of such destructive funguses as smut, anthracnose, fusarium, leaf spot, black rot, root rot, and various other plant, leaf and root diseases. Various highly important medicines, which it is not within the scope of this talk to even enumerate, have come from the work of the chemist and the biochemist with coal tar intermediates.

It is very interesting to speculate as to the outcome of the application of modern synthetic chemical methods to the production of oxygen—and nitrogen—containing derivatives of the coal tar intermediates. The manufacture of phthalic anhydride by passing a mixture of naphthalene and oxygen over a metallic oxide is a notable example of the type of advances to be expected. Ever since Kekulé and Frankland and Kolbe began to clear up for us the mystery of the structure of the benzene ring, the question of the synthesis of such useful products as benzene and toluene, naphthalene, anthracene, and their derivatives, has agitated the minds of chemists. During the war the acute shortage of toluene which was created by the unprecedented demands for high explosives and particularly for T. N. T., resulted in the production of this highly useful hydrocarbon by various chemical methods. None of the processes for preparing toluene, which the war demands brought into active production, have furnished toluene at a price which will make it available for ordinary peace-time consumption. Some of the war-time processes for the manufacture of toluene involve the cracking of such materials as solvent naphtha and high boiling naphtha, and it is probable that further attention to the cracking of coal tar fractions will result in the development of products of enhanced value. Then, too, there is the application of such materials as aluminum chloride to the direct synthesis of other hydrocarbons from those which ordinarily occur in coal tar. It is not improbable that the direct production of

some of these very useful hydrocarbons will be again attempted. Our knowledge of the application of catalysts and of pressure and temperature to the synthesis of hydorcarbons and carbohydrates may find an application in this field, provided the demand for intermediates of this type justifies the expenditure of time and money required for this work.

The direct preparation of aniline from benzene, or, better still, from carbon, hydrogen and nitrogen, and the preparation of its homologs, such as the toluidines, the preparation of naphthylamine and of anthraquinone and the amino-anthraquinone, may be a logical development of the further application of research to the problems of coal tar chemistry. The acids and alcohols of the aromatic series no doubt would find new and useful applications if they could be produced at diminished costs. These classes of oxygen-containing derivatives of coal tar intermediates may, too, come in for attention in the development work of the immediate future.

There has been a great deal of discussion in the technical literature and trade journals, as well as in connection with the meetings of some of the sections in Pittsburgh, of the subject of "Synthetic Motor Fuels." Considerable advance has been made in the preparation of liquids suitable for use in the internal combustion engine, from coal as an ultimate raw material. The use of benzene as a motor fuel, and in particular the fact that benzene motor fuel can be used without giving rise to knocking in the motor, naturally raises the question whether it may be possible to synthesize this very useful motor fuel more cheaply than it is possible to recover it from the coal tars which are now practically the sole commercial source of this material. Then, too, the vast number of useful products which are derived from benzene, in the classes of dyes and pharmaceuticals, give great importance to the question of the cost of this indispensable raw material.

The impregnation of wood for the preservation, both against the attack of destructive fauna and flora, as well as against the weathering action of sun and rain, has come to be a well established industry and takes quite a considerable portion of certain fractions of coal tar. If preservative liquids of this type, with coal tar as the base, and in clear, attractive colors, could be developed, no doubt the field of application of these preservatives solutions and stains would be considerably widened. We would have not only the useful shingle stains, but houses of wooden construction could be attractively treated and properly preserved against the deterioration brought about by weathering. This subject is worthy of further study.

It would seem that it is only the backwardness of our industrial development, which is in turn conditioned by the incompleteness of the work of the chemist, which permits of the destruction, as a fuel, of these potentially valuable carbon, hydrogen and nitrogen compounds which we term "coal tar." It would seem to be an economic waste to destroy such material as this, merely for its fuel value, when the

possibilities of these materials in the hands of the synthetic organic chemist are almost inexhaustible.

In opening the discussion, the following questions seem pertinent:

Mr. Church's Paper: The question of the nature of the preservative action of tar acids—we know of their effect in preventing the growth of destructive fungus. Do they not also exert an opposite effect?

Dr. Weiss's Paper: What is the effect of recirculation of non-condensable still gases on the tar acids?

Mr. Crawford's Paper: Has Mr. Crawford's proposed scheme been operated commercially?

Dr. Oshima's Paper: I have in mind the catalytic effect of metals and would like to ask if Dr. Oshima's work was carried out in glass apparatus.

S. R. CHURCH. Replying to Dr. Stine—The wood preserving value of tar acids in creosote oil is an open question, although in this country specifications usually do not require a definite percentage of these bodies. They are more volatile and more soluble in water than the higher boiling hydrocarbons which constitute the major part of the oil.

Service tests over long periods of years indicate that any creosote obtained from high temperature coal tar is a good preservative; its lasting value depends to a considerable degree on the distilling range of the oil.

When a new preservative is offered, service tests are not available and we are seeking for accelerated tests that will give us indications as to the degree of stability, chemical and physical, of its constituents.

I am glad that Dr. Stine clarified and amplified my statement to the effect that the percentage of coal tar finding its way into organic chemicals has not been increased for the past forty years. I do not mean to imply there has been no advance in the chemistry of coal tar derivatives—as I pointed out advances have been made in the direction of new dye stuffs and new fields of utilization—but the point is they come from the coal tar derivatives of forty years ago, and I doubt if we have a new derivative, at least with one or two exceptions.

JOHN MORRIS WEISS. Answering Dr. Stine—I think there is only one question, and that is the effect on the tar acids of the recirculation method of distillation. So far as phenol and cresol, there is not much effect. They come over at the lower end of the distillation, and if there has been any effect on the actual yield, I have not noticed it.

ROBERT M. CRAWFORD. Answering Dr. Stine—The scheme I propose has not as yet been operated on a commercial basis but is projected.

A MEMBER. I would like to ask about the sulphur content of the phenols recovered by your sodium sulfide extraction.

ROBERT M. CRAWFORD. We have been able to limit sulphur to the present specifications of the commonly marketed acids. So far, we

have found no difficulty in removing sulphur compounds by the present method of doing so. At this point, it might be well to remark that by extracting phenols with sodium sulfide, we find a marked decrease in absorption of neutral oil, naphthalene, etc., as compared with extracting phenols with caustic soda. It is possible to purify a sodium sulfide phenolate in a fraction of the time required to purify a caustic soda phenolate simply due to the fact that the impurities are less soluble in sodium sulfide than they are in caustic soda. In some cases, we have obtained crude phenols which are very nearly transparent.

A MEMBER. We have a problem of extracting phenol which is present in solution—a very small percentage. I was wondering if that sodium sulfide could be used to get the phenol out of the water solution?

ROBERT M. CRAWFORD. Yes, indirectly by first extracting the phenol from the solution with benzol and then absorbing phenols from the solvent extract with sodium sulfide. I presume you refer to the removal of phenol from coke plant ammonia liquor. We have found the process to work admirably on a case of this kind.

A MEMBER. Why does Mr. Crawford object to the manufacture of synthetic phenol?

ROBERT M. CRAWFORD. I believe benzol has more value as a motor fuel than it has in the manufacture of synthetic phenol. We must remember that aromatic hydrocarbons stand first in the list of anti-knock compounds, and I do not believe the American chemical industry should be required to manufacture phenol synthetically when we consider that we are throwing away or burning considerable quantities of natural phenol.

WILLIAM J. HALE.* I do not agree that the manufacture of synthetic phenol should be discontinued. The time is coming when it can be made by the catalytic oxidation of benzol cheaper than natural phenol What do you think, Mr. Weiss?

JOHN MORRIS WEISS. Our work on the catalytic oxidation of benzol led to the formation of maleic acid instead of phenol. But there is still a distinct possibility of making phenol this way.

WILLIAM J. HALE. Still I think it can be done.

A MEMBER. When will we make aniline from benzol catalytically?

WILLIAM J. HALE. I think that will come. Do not you, Mr. Weiss?

JOHN MORRIS WEISS. I think it will, undoubtedly.

YOSHIKIYO OSHIMA. Answering Dr. Stine—Our work was carried out in a fused silica tube.

CHARLES M. A. STINE. At what temperature?

YOSHIKIYO OSHIMA. At 850°C. We tried several temperatures but in this experiment, 850°C.

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UTILIZATION OF BITUMINOUS COAL IN THE MANUFACTURE OF WATER GAS

By W. H. Fulweiler

The Manufacture of Water Gas

The manufacture of water gas consists essentially of two steps:

(1) The storage of heat in the fuel bed of the generator and in the checkerbrick of fixing vessels, and combustion of the fuel with an air blast (1).†

(2) Utilization of the heat thus stored and the decomposition of steam in the presence of carbon in the fuel forming water gas(2). In the case of carburetted water gas there is the further step of the enrichment of the water gas by the vaporization of oil in the presence of hot blue gas in the fixing vessels.

The fundamental chemical reactions are, therefore, in the first step the combustion of carbon in accordance with

$C+\frac{1}{2}O_2=CO+29{,}200$ calories or + 52,560 B.t.u.

$C+O_2=CO_2+97{,}000$ calories or + 174,600 B.t.u.

and in the second step, the decomposition of steam by carbon in the sense

$C+H_2O=CO+H_2-29{,}200$ calories or — 52,560 B.t.u.

$C+2H_2O=CO_2+H_2-19{,}400$ calories or — 34,920 B.t.u.

The combustion of carbon in the first step of the process must furnish the latent and sensible heat in the illuminating gas; the latent and sensible heat in the blast products; radiation and convection and other losses and in the second step, the carbon required to combine with the steam in the formation of blue gas.

It is evident, therefore, that the fuel in the manufacture of water gas must contain sufficient carbon to combine with steam and in addition, be capable of liberating about an equivalent amount of heat on combustion with air.

General Statement of the Fuel Problem

On such a theoretical basis, a high percentage of carbon in the fuel would not be necessary, but from a practical operating viewpoint, other

†Numbers refer to references at end of this article.

things being equal, the fuel that contained the highest percentage of fixed carbon will evidently be the most desirable.

The writer discussed this subject a number of years ago and showed hat in practical operation, there were several points to be considered (3).

(1) The amount of fixed carbon available in the fuel.
(2) The amount of ash in the fuel and the fusing point of ash.
(3) The amount of moisture.
(4) The amount of volatile combustible.

He pointed out that roughly every 1% ash reduced the useful amount of carbon by 2%; that 1% moisture reduced the carbon by 1.11% and that up to about 7% the volatile might be considered equally useful for the fixed carbon.

The general subject was summarized by the conclusion that the best fuel was that which would deliver the maximum useful amount of carbon with a favorable ash content at the lowest cost per unit of carbon delivered.

Mr. E. F. Pohlman (4) some five years ago calculated the comparative value of a generator fuel and discussed this question on a somewhat similar basis. He assumes that pure carbon would have the value of 100 and he makes the following deductions.

For the deficiency of fixed carbon, i. e., 100%—% fixed carbon;

For the fuel to be used in evaporating moisture, .8% of the moisture;

For the fuel unrecovered in the clinker, 20% of the ash;

For the loss due to ash and cleaning time, 1.16%×% of ash, and then credits for the volatile matter by adding one-third of the volatile matter.

In the discussion of Mr. Pohlman's paper it was pointed out that it was very difficult to give the proper value to the effect of the fusion point and composition of the ash.

It is well known that the fusion point of ash from different coals and cokes varied quite widely from below 2000 to above 3000°F. (5) and that moreover the character of the ash, that is, its percentage of iron, etc., has a very considerable effect on the nature of the clinker formed. Two coals with approximately the same melting point may clinker quite differently: one coal may give a tough stringy clinker that

is hard to remove, while the other, due to the different chemical composition, may give a pulverant brittle clinker that can be removed very easily.

While the above represents our general views regarding the most suitable generator fuel when fuels of high fixed carbon content are under consideration, when we consider the use of bituminous coals with a high percentage of volatile, it is evident that we must revise these specifications and this revision will be considered later.

In the early days of the manufacture of water gas anthracite coal was quite generally used, as it was a very satisfactory generator fuel, being reasonably low in ash, generally with a high fusing value, high in fixed carbon and low in volatile and moisture.

With the extension of the use of water gas apparatus and with increasing mine cost and freight rates on anthracite coal, both oven and retort coke were used as generator fuel. These fuels usually contain somewhat higher ash of a less favorable fusing point, but their use was generally satisfactory.

Where coal gas plants were operated adjacent to water gas apparatus the use of hot coke as drawn from the retorts resulted in a decided saving in fuel of the order of 1 to 2 lbs. in spite of the larger percentage of small coke and fines and became very general practice.

Economic Reasons for Use of Bituminous Coal

In spite of the very general and successful use of anthracite coal and coke there were a number of arguments for the use of bituminous coal as a generator fuel.

Bituminous coal is cheaper than coke.

It is more generally available.

It would therefore, carry a lower freight rate.

This differential in the delivered price between coal and coke has varied considerably during the last 25 years. Taking an average of some 30 plants scattered throughout the United States for about 20 years there was a differential of $2.50 to $3.00 per ton. This differential gradually increased, and shortly after the war it arose to some $5.00 to $6.00 per ton. Since that time it has been decreasing again and for the year 1926 the average of 30 plants previously mentioned showed that a suitable bituminous coal for use in water gas generators was about $2.34 per ton cheaper than a coke and in many cases bituminous coal of less favorable composition can be secured at considerably lower

prices. There is, therefore, a very strong economic incentive to use the lower priced fuel if it can be made to give equally satisfactory operating condition.

HISTORY OF EARLY EXPERIMENTS

There seems to be little if any information regarding the first use of bituminous coal as generator fuel. Evidently when used in the existing types of generators it was not successful, as we find that the attentions of the investigator and inventor were concentrated upon the construction of special forms of water gas apparatus, particularly adapted for the utilization of bituminous coal.

F. N. Morton (6) in his paper "A Half-Century History of Water Gas" (1909) mentions three types of water gas apparatus adopted for the use of bituminous coal and still a fourth is described by O.

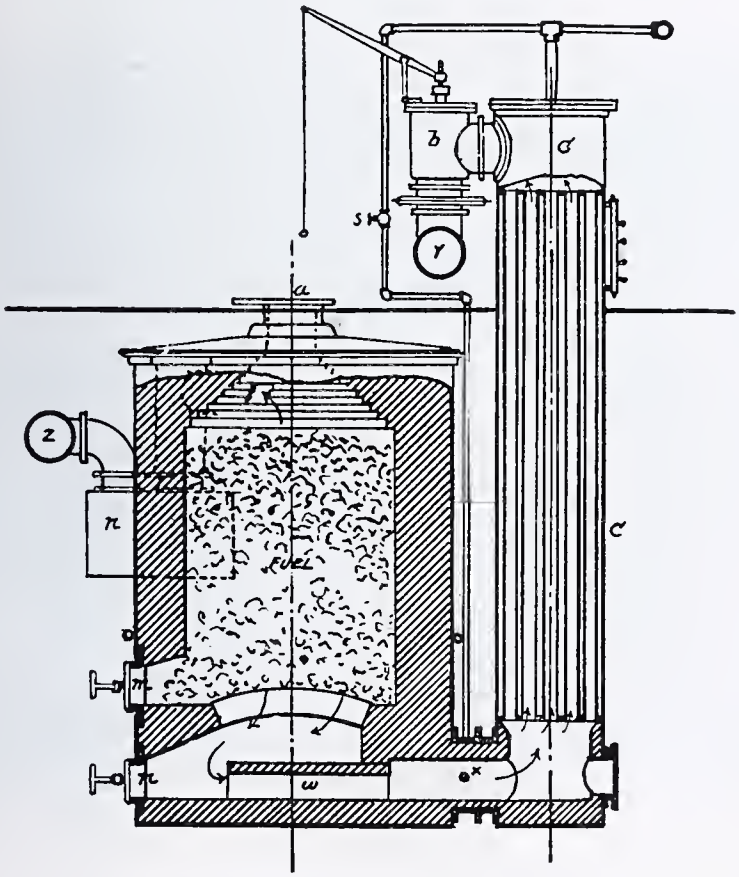

FIG. 1. LOOMIS GENERATOR

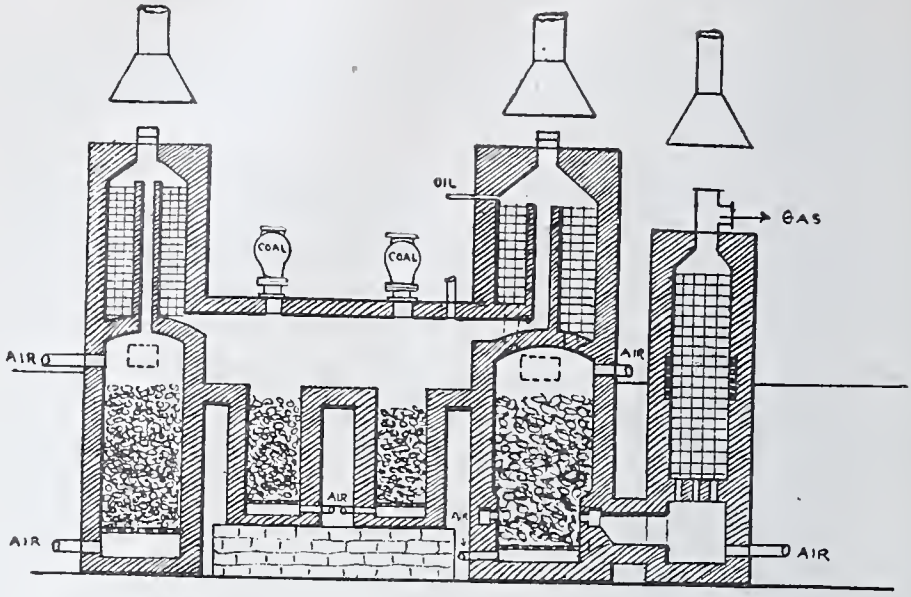

FIG. 2. ROSE-HASTINGS GENERATOR

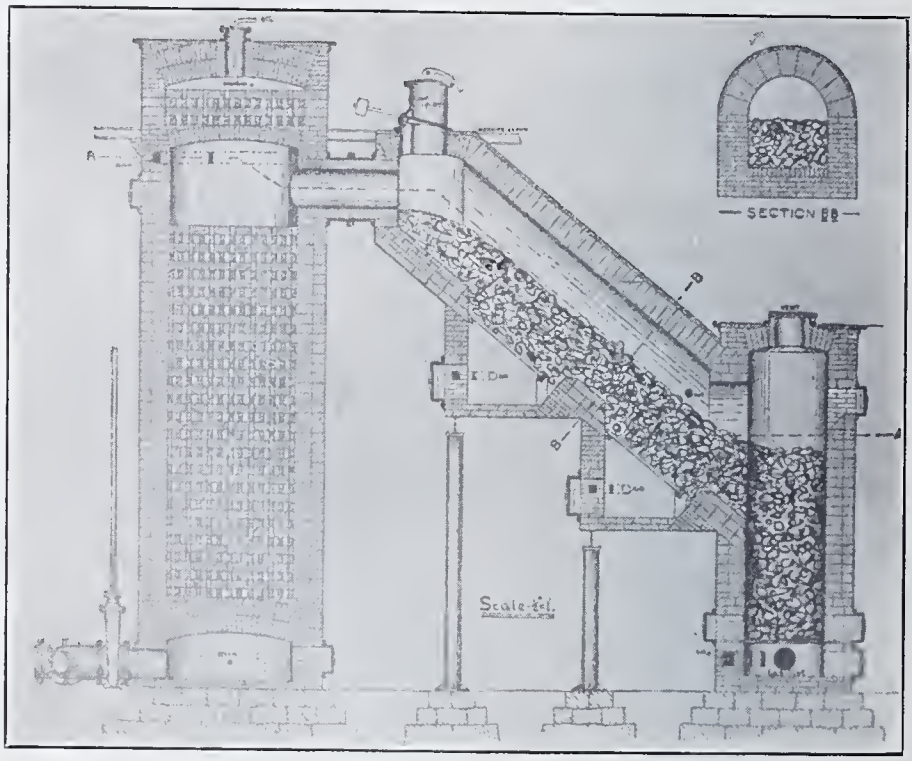

FIG. 3. REW PROCESS

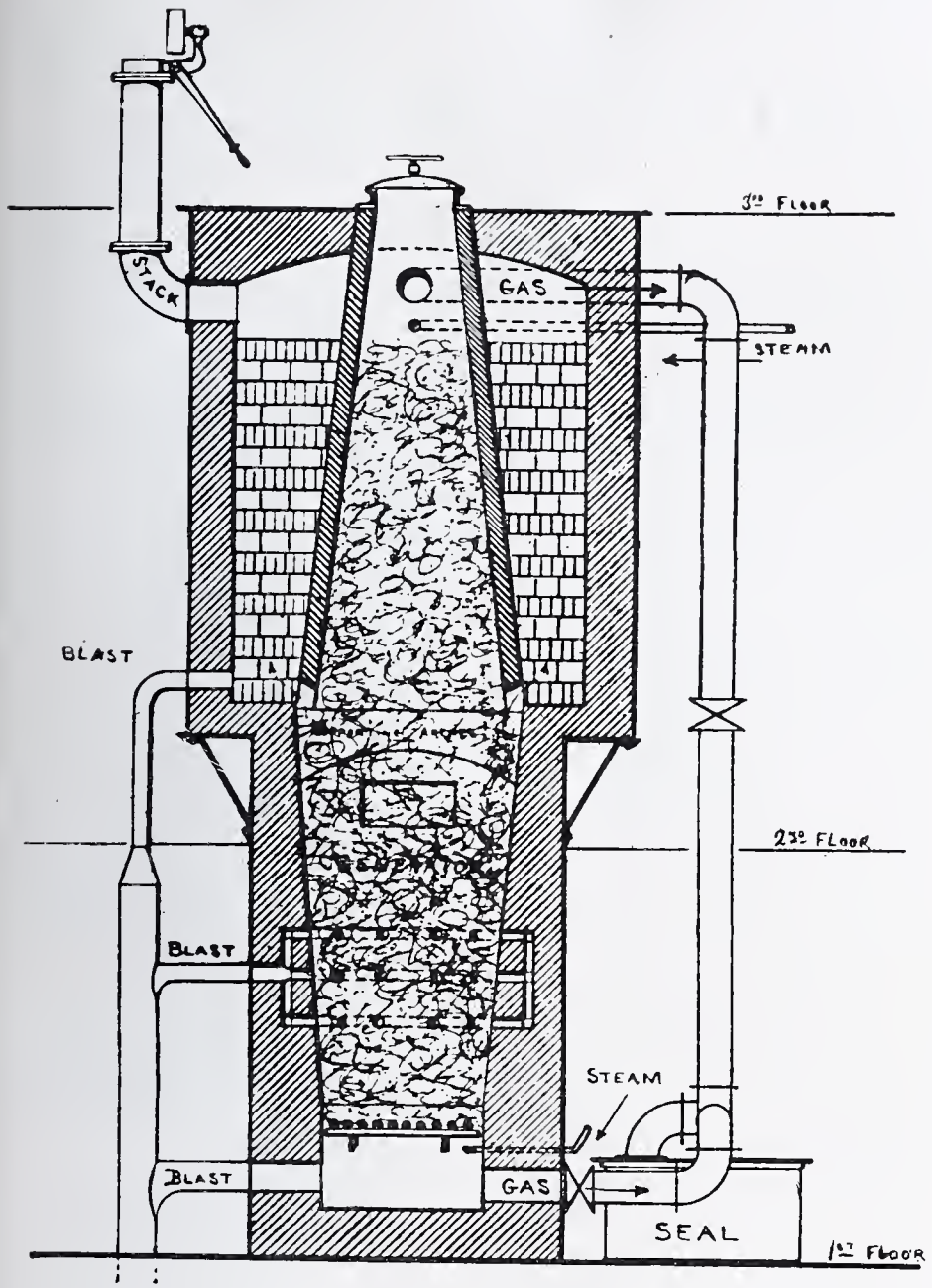

FIG. 4. FAHNEHJELM GENERATOR

B. Evans (7) in a paper, "History of the Development of Water Gas" (1915).

One of these types belonged to the Loomis system(8), Fig. 1, the generators of which were used generally for producing fuel gas. However, plants were erected in Cottage City, Mass., and Sandusky, Ohio, to furnish illuminating gas. These latter were designed for the use of soft coal. The generator was built for down runs and blows and the superheater was provided with partitions of fire brick instead of checkerbrick in order to eliminate trouble with ashes or soot.

Another apparatus—of exceptional construction—was the Rose-Hastings(9), Fig. 2, erected at Westchester, Pa., and Elkhart, Ind., and intended for the use of soft coal. The outstanding features of the apparatus were four fuel beds all connected together. Oven coke was contained in one bed while mixtures of coke and soft coal were used in the others. During operation all the fires were blown simultaneously, followed by steaming of the mixed fuel beds. The resulting gases were led through the superheating chambers and then fixed by passing through the coke fire.

A third type of apparatus, the Rew(10), Fig. 3, was used by the National Gas & Water Company of Chicago. The chief feature was the inclined retort between the generator and superheater used for coking the soft coal. The coal was coked by the sensible heat of the gases passing over it. The above apparatus was usually erected in pairs, the system of operating being to blast each fire simultaneously during the blow. When making a run, the steam was passed up through one superheater; down over the coal in the retort; through the first and second fuel bed respectively; upward over the soft coal in the second retort and the gases carburetted with oil at the top of the second superheater, subsequently being fixed by their passing downward through this vessel.

A fourth type, known as the Fahnehjelm(11), Fig. 4, was a water gas generator constructed so that, if desired, bituminous coal might be used. The main feature was the extension of the generator up into the superheater so as to form a retort for the coking of the soft coal. The chief disadvantage of this type was the inability of the retort to furnish a sufficient supply of coke for the generator.

An interesting feature of this apparatus is that it is the prototype of many of the present systems proposed for complete gasification.

For various reasons these special types of apparatus did not prove successful and they have disappeared, while the Lowe type of apparatus is almost universally used.

The earliest recorded figures regarding the use of bituminous coal in the production of water gas in the usual type of generator were found by the author to be those given by W. S. Bowen (1895)(12), at a meeting of the Ohio Gas Light Association. Mr. Bowen describes the operation of an auxiliary water gas plant in Louisville, Ky., which was used during the cold weather to supplement the natural gas supply. The type of apparatus was not named, but it possessed a cupola at the top of the generator which served as a retort for coking the coal. The operating procedure consisted in blasting the fire for 4 to 5 minutes, with the subsequent addition of 50 to 60 pounds of coal followed by a steam run of 10 to 12 minutes. During the run the water gas passed up through the coal, taking the coal gas along with it. This mixture then was carburetted with oil gas and fixed in the superheater over a bed of red hot coke. No troubles with the fire were experienced and in general it gave a wholly satisfactory performance. As an item of interest, the average estimate of the materials used per 1000 cu. ft. of gas was

Bituminous coal	30 lbs.
Coke	5 lbs.
Oil	2.5 gals.

Further inquiries regarding the advantage of using bituminous coal or a mixture of bituminous coal and coke in water gas generators was made at the meeting of the Ohio Gas Light Association in 1903(13). Both favorable and unfavorable reports were received. W. H. Baehr, Superintendent Gas Department, Denver Gas & Electric Co., Denver, Colo., told of using straight lignite in a water gas generator. The method of operation was to blast the fire, add a charge of lignite and allow the coal gas to be driven off by the heat. After the major portion of the coal gas had passed off, the steam was turned on for the production of water gas. Results were satis-

factory as to cost and practical running at that time.

Today, the chief objection to such operating methods would be the low capacity of the set. It is believed that a search through the records of every large gas company will develop experiments in the use of bituminous coal at various times and with usually unsatisfactory results.

Reasons for Lack of Success

In reading over the papers recounting the development of the use of bituminous coal as a water gas fuel it will be seen that the experience was very much the same for each water gas plant and it would seem advisable to mention at this point the troubles and disadvantages which made the use of bituminous coal objectionable as a fuel in water gas generators. Briefly, they are:

(a) Reduced capacity of the set.
(b) Matting and arching of the fuel.
(c) Numerous blowholes or "flues" and uneven combustion.
(d) Sidewall clinker.
(e) Blown over fuel.
(f) Waste fuel in blast gases.
(g) Regulation of the temperature in generator, apparatus, carburetor and superheater.
(h) Sticky valves.
(i) Tar emulsions.

It must also be remembered that in practically all of this early work on bituminous coal the plants were operating under an illuminating value standard. Under such conditions, the composition of the gas became of very considerable importance on account of the fact that, for example, a 1% increase in CO_2 would reduce the candle power 3½% and 1% nitrogen would reduce the candle power 3%; and since the heating value was not of importance, it was necessary that we should make the highest possible quality of blue gas with the lowest quantity of CO_2 and nitrogen in order to secure the maximum efficiency. Again, in much of the early work accurate methods for measuring the steam and the air and the temperature were not available and the conditions were usually maintained by more or less empirical methods.

It is believed that one of the most important reasons for the present success of bituminous coal as generator fuel is the fact that we are

now operating under a heating value standard, and it is our object to extract from the coal the maximum amount of B.t.u.'s in the gas formed that can be economically enriched to give the desired heating value. In other words, it is the total amount of heat that can be extracted that is now of importance rather than the necessity of producing a blue gas of any specified composition. This latter fact has permitted the use of the blow run which in the writer's opinion has been a most important factor in the economic development in the use of bituminous coal. To the above we must also credit the modern methods of controlling operating conditions such as the air and steam meters, pyrometers, the use of automatic control for the operating mechanism and the installation of waste heat boilers and the back run and down run to conserve the sensible heat in the off-going products.

Development of Modern Methods

The modern developments in the use of bituminous coal may be said to have commenced actively about 1913. Successful results had been obtained by Mr. G. W. Wallace(14), East St. Louis plant revived interest in this subject.

A great deal of experimental work was carried on by various plants, particularly those in the mid-west, very probably as the result of the success obtained at East St. Louis and we may refer to the work done in 1918 by A. C. Howard (15) of the United Gas & Electric Engineering Corporation on the use of bituminous coal in water gas generators at Bloomington, Ill.

In July, 1918, W. A. Dunkley (16) and W. N. Odell (17) made a survey of the water gas plants in Illinois and the neighboring states to determine the status of bituminous coal as a generator fuel. They found that considerable progress had been made and a saving in the cost of fuel was being effected. At the same time it was obvious that many improvements could be made in the mode of operation with a view to overcoming certain disadvantages.

In an attempt to improve these methods of operation, a series of experiments was carried out on a commercial scale at the Streater Plant of the Public Service Company of Northern Illinois (18).

One of the most outstanding improvements used in the manufacture of water gas with bituminous coal was introduced during these

experiments, i. e., the blow run, about which more will be said later.

Since these experiments considerable work has been done by W. W. Odell (19) at the instigation of the Bureau of Mines and the Illinois State Geological Survey on the successful use of bituminous coal in water gas sets. These tests have resulted in the improvement of fire and fuel bed conditions with corresponding increase in the capacity of the set and detailed study of operating conditions in general.

As a result of the work that has been done upon the problem, we may see that the operating conditions necessary for the use of bituminous coal have been developed to such a point that its general use is now limited purely by the economic conditions existing at any particular plant, as the technical difficulties which formerly surrounded its use have either been overcome or eliminated.

Action of Bituminous Coal in Generator

In considering how these difficulties have been overcome, we must consider briefly the difference in the behavior of bituminous coal in a water gas generator and the effect that this behavior has on the subsequent operations of the apparatus. The most important objection to the use of bituminous coal was the reduction in gas making capacity, especially with larger sized generators. In the small generators the reduction is rather small, but with the large generators it would amount to 50% and evidently this reduction in capacity depended upon the condition of the fire (20).

Experience has indicated that a bituminous coal fire does not present as uniform a condition as one of coke or anthracite coal and such fires show evidence of matting at the top, blow holes and channeling at the sides along the walls and with cold centers and evidence of very high temperatures along the walls. These conditions are evidently due to certain fundamental changes which take place with bituminous coal on heating and which do not affect anthracite coal or coke. Evidently, there is less resistance to the flow of air and steam around the walls of the generator than through the center, and in charging the fuel there is a tendency for the larger lumps to roll to the outer portions of the fire, leaving the smaller lumps in the center.

When the set is under blast the greater flow of air along the walls results in a rapid composition with a production of high temperature and the rapid coking of coal in contact or close to the wall areas. This

has a tendency to further decrease the resistance and to accentuate the flow of air and steam through this zone.

During the run the steam follows the air and since practically all of it passes around the periphery of the generator the time of contact is short, the area of coke is relatively small compared with what would normally be present in the whole fuel bed and the capacity of the set is reduced. At the same time the heat is gradually penetrating into the mass of coal fuel and as this reaches the plastic state the resistance to the flow of steam and air is increased. More and more air passes around the outside causing the formation of blow holes, mechanically carrying over a considerable quantity of finer fuel into the fixing vessels and resulting in a generally unsatisfactory fire condition.

In the early stages of the work with bituminous coal the formation of the central core of uncarbonized fuel was found to be the cause of blow holes and attempts were made to break this up by barring down from the top. This resulted in danger of burning the operators and was only partially successful, as the core would almost immediately reform. Attempts were then made to prevent the formation of this core by using shoots which would distribute the coal to the outside of the generator, thus attempting to throw the finer lumps to the edges and leave the larger lumps in the center(21).

Use of Coal and Coke Mixtures

The most successful method of preventing the formation of the unburned core of fuel and keeping the whole fire open and active was by mixing 30 to 50% of coke or anthracite coal with the bituminous coal(22). By operating in this manner, the fire was kept active throughout its cross section and the capacity was restored to normal. Many plants are operating today with such coke and coal mixtures, but the objection to this method of operation is that two types of fuel must be handled and the possible saving by the use of cheaper fuel is reduced.

Use of Special Coals

As a result of all the work that has been done with bituminous coal it has been found that there is at least one and there are possibly other seams of coal that have such physical characteristics

that when used free from the small sizes they will not form the core of unburned fuel and will retain their form under the influence of temperature so that the whole fuel bed will remain active in much the same fashion as a coke fire. While coals of this type are apparently very restricted and would not be generally available, due to freight rates, they have given very successful results. Such coals must be very carefully prepared and handled from the mine to the generator in order to prevent breakage and they are generally screened again just before charging. The necessity of this repeated screening and disposal of the small sizes of coal would evidently prevent the use of these special coals as a general solution of the problem, but where they are available they have given very successful results.

Development of Pier Process

A third method of operation is that known as the Pier process(23). This is the joint invention of Mr. W. J. Murdock and Mr. E. A. Lungren of the Coal Products Company and Mr. O. B. Evans of the United Gas Improvement Company. This process was developed after a number of years of experimental work in endeavoring to satisfactorily utilize the local Illinois coal that was available at relatively low prices.

This process was based on the observation that the active zone in the generator fire when using bituminous coal extended from 18 to 24" from the walls; that the high temperatures developed next to the wall made this section of the fire equivalent to a retort; and that the coal was coked by the combined influence of the conducted and radiant heat. This observation explained how generators approximately 3 to 4 ft. in interval diameter could be operated with practically no loss in capacity while generators of 8 or 9 ft. internal diameter had their capacities reduced approximately 50%.

It was found that by removing the uncarbonized core of coal and replacing it with a refractory pier there was then set up a second active zone surrounding the pier for 18 to 24"; and if the pier was so proportioned that no portion of the fuel bed was more than 18 to 20" from a refractory surface the whole bed was active and there was no formation of an inactive core, blow holes were eliminated and the capacity of the generator was restored.

In other words, when operating with bituminous coal the capacity of

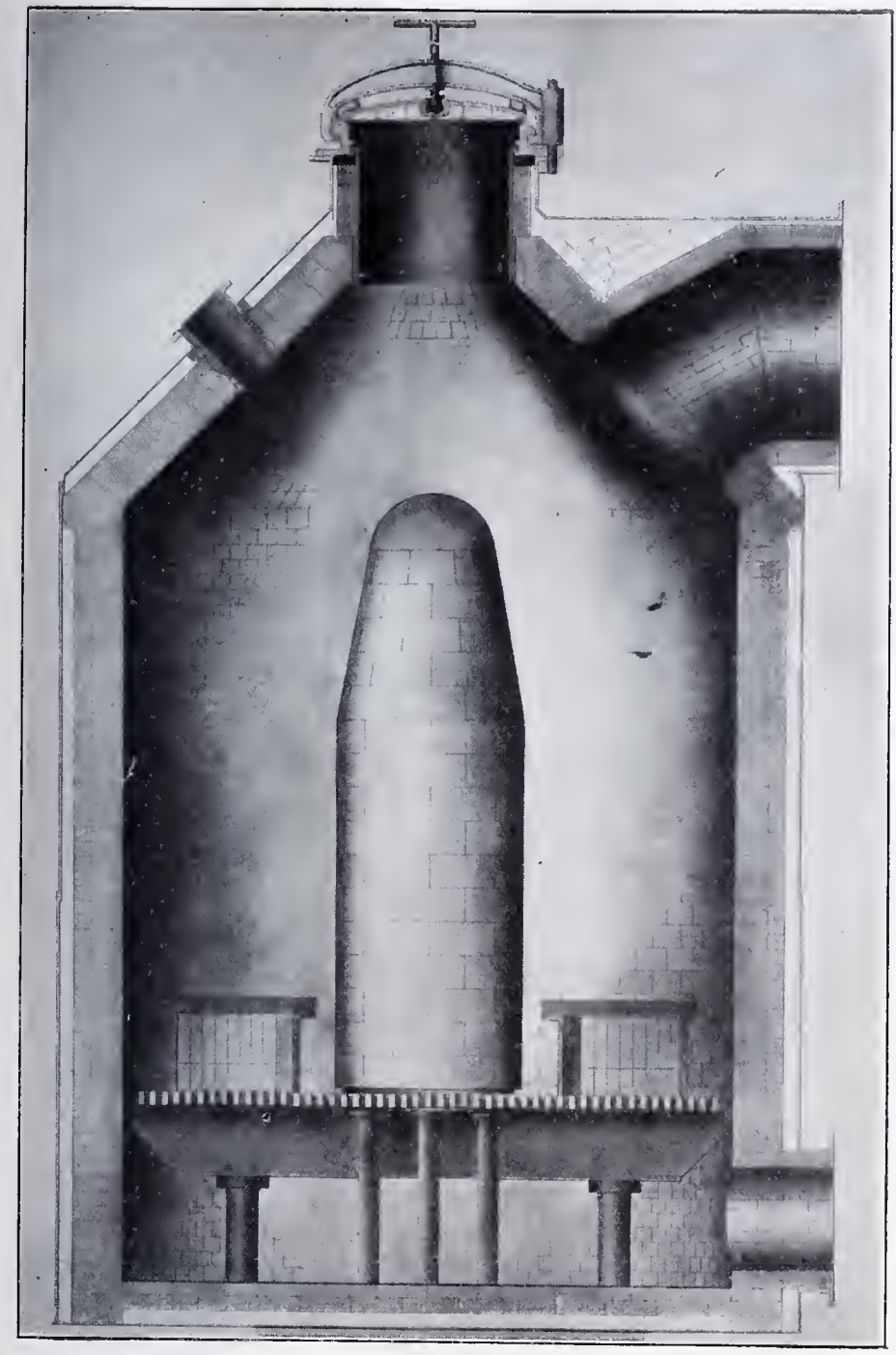

Fig. 5. The Pier Process

the generator was dependent upon the coking capacity of a retort 18" in depth and whose area was the periphery of the refractory linings against which combustion could take place, rather than depending upon the area of the grate surface. While this would appear to be a very simple step, yet successful results required a very considerable amount of experimental work in determining the proper size and construction of the piers. Fig. 5 shows a pier installed in a modern generator 9 ft. internal diameter. In this generator the pier is 3 ft. in diameter, so that no portion of the fuel is more than 18" from a heated surface.

It has been found that due to mechanical difficulties it is hard to install piers in generators much smaller than 9 ft. internal diameter. The same results can be obtained by building a cross wall in the generator of refractory material. This gives the same effect of the additional hot surface for carbonization and is not subject to mechanical limitations of tipping.

The introduction of the pier or its equivalent cross wall has successfully eliminated all the objections to the use of bituminous coal and has permitted the successful operation of the largest generators.

The capacity of the machine with a suitable grade of bituminous coal is practically equivalent to the same machine operating with coke, although with less suitable fuel, particularly as regards fines, the capacity may be reduced by about 10 to 15%.

The efficiency of operation has been considerably increased, as due to the higher heating value of bituminous coal from 2 to 5 lbs. less fuel is required than with coke.

Blow Run

As mentioned before, one of the important features of the operation with bituminous coal is the use of the blow run. This consists essentially in diverting the rich producer gas formed at the end of the blow into the holder by shutting off the carburetter blast and closing the stack valve from 10 to 17 seconds prior to the beginning of the run or the addition of steam. The blow run thus allows additional blasting time for the fuel bed and conserves the high heating value of gas at the end of the blow where the heating value may rise to 135 to 150 B.t.u.

It is obvious that the use of the blow run(24) considerably increases the capacity of the set; but since the blow run gases are essentially a rich producer gas they contain considerable quantities

of inerts and the amount of blow run gas used must, therefore, be regulated, having regard to the result in the increase in specific gravity of the gas and the loss in heating value which must be made up by the use of additional oil.

However, in view of the increase in the heating value of blue gas made with bituminous coal over that made with coal, with careful operation there need be no increase in the amount of oil used per 1000 ft. of gas even with the blow run.

The use of Young-Whitwell back run process (25) and the Chrisman down run process (26) have both been found advantageous with the use of bituminous coal and have resulted in substantial savings in fuel.

General Conditions for Successful Results

Certain general conditions have now been worked out which appear to be important in insuring successful results.

One of the most important requirements is that the coal should be of suitable quality, that it should be free from small sizes and fines, and should preferably be 3″ to 6″ in size.

When coal was first used in water gas sets no attempt was made to screen or fork it(27). It was found that upon charging the large lumps rolled toward the periphery, while the fine material remained in the center. As a result, the top of the fuel formed a more or less impervious mat upon coking. This condition caused the blast to pass through the loosely packed lumps along the generator walls, leaving a mass of relatively cold and green fuel in the center of the bed. In such a fuel bed channeling or blow holes were plentiful. It will be seen that the blown over fuel, which is a result of fine coal being present in the generator, will be greatly increased when blow holes are present. The velocity of the blast is considerably increased by the presence of such channels and will have the tendency to carry over a larger percentage of heavier particles.

Large volumes of smoke produced by charging the bituminous coal are now eliminated by using a blow run followed by the regular steam run immediately after charging. In this manner, most of the volatile matter given off by the coal is passed directly into the relief holder. During the blast the quantity of smoke is reduced to a great extent by the use of secondary air(28).

Sticky valves seem to be a necessary adjunct to the use of bituminous coal where the apparatus is not in continuous use. However, remedies have been found in lubricating the valves by means of gas oil or graphite(29).

TAR FORMATION

When bituminous coal was first utilized in water gas manufacture some trouble was experienced due to the formation of emulsions, and although Mr. Odell (30) in his papers has claimed that water gas tar should separate more freely when bituminous coal was used this does not seem to be true until after coal has been used for several months. The formation of emulsions appears to be due principally to the fire conditions in the generator and when these have been satisfactorily adjusted the emulsion trouble disappears.

The use of bituminous coal alone in the manufacture of blue water gas produces a relatively small amount of very heavy tar and this naturally has some influence on the water gas tar produced when carburetted water gas tar is manufactured. Table I gives some analyses of water gas tars made by the use of bituminous coal and also the coal tar produced when no oil is used.

BLAST PRESSURES

Another very important fact that has been developed is that the blast pressures commonly used with coke are too high for the use of bituminous coal and would result in the blowing over of a large percentage of fuel in the carburetor and other fixing vessels and would have a greater tendency to the formation of blow-holes in the fire. As a result, it has been found necessary to reduce the blast pressure to about 20 to 22″ water and decrease the volume about 30%. It has thus been found possible to operate very satisfactorily with a minimum amount of trouble from blown over fuel.

The installation of the so-called checkerless carburetor(31) with atomizing oil sprays eliminates all difficulty from blown over fuel In this manner any fuel that is blown over can be readily removed at a minimum of trouble and stoppage, and increase in back pressure throughout the set is eliminated.

With the better knowledge of the methods of operation it has been found that less steam is made in the waste heat boiler in the use of

TABLE I

ANALYSIS OF CARBURETTED WATER GAS TAR AND COAL TAR

	W.G. Tar Coke Fuel	W.G. Tar Coal Fuel	Coal Tar from W.G. Generator	Coal Tar from W.G. Generator
Position Taken	Average	Average	Wash Box	Relief Holder
Specific Gravity, Dry Tar @ 25° C.	1.062	1.084	1.208	1.127
Free Carbon by CS_2 % by wt.	0.30	.67	10.4	9.4
Viscosity Engler @ 40° C.	3	3.5	....	16
Flow Test @ 50° C. Seconds	....	....	233	....
Tar Acids % by volume	Nil	Nil	1.5	1.5
Naphthalene, lbs. per gallon	0.58	.53	Nil	1.33
Unsulfonated, % by volume	7.4%	....	Nil	0.3
Distillation:				
Oil to 170° C. % by wt.	Nil	1	Nil	Nil
" " 200° C. "	3	4	Nil	Nil
" " 235° C. "	18	17	Nil	28
" " 270° C. "	45	37	3	39
" " 300° C. "	56	47	8	46
" " 315° C. "	61	52	13	49
" " 360° C. "	76	72	32	62
" " Coke "	86	80	67	79

bituminous coal than with coke, and by the proper use of tertiary air blast the smoke nuisance has been reduced to a minimum.

EFFECT OF NATURE OF COAL

The nature and physical characteristics of the coal used as fuel have an important bearing on the ease of operation and the results obtained. We have had to modify our views regarding what will constitute the most efficient generator fuel from those previously expressed where a minimum of volatile is required.

At the present time, the stack of a water gas generator is down about 65% of the time, so with other things being equal, we would anticipate recovering roughly 65% of the volatile products. As a matter of fact, experiments seem to indicate that due to the high temperatures existing in the fuel bed during the blow, although the time was short, the effect of the increased temperature was such that we only recover in the gas some 55 to 60% of the volatile matter in the coal.

Under such conditions, we would anticipate that we should credit the coal with say 50% on the volatile matter and on such a basis the lower volatile coals would apparently have a higher value. Experience, however, does not seem to confirm this and where other condi-

tions are the same, the high volatile gas coals, those containing from 30 to 35% volatile matter, appear to give the most satisfactory results. In other words, we are able to efficiently utilize the high heating value of the volatile constituents.

There has been no well defined criterion of the suitability of coal except its actual test in the generator. Apparently, the non-coking coals have not been as efficient as those coals having a certain amount of coking ability. In other words, a moderately coking coal such as represented by the block or splint type of coal appears to be more satisfactory.

The melting point and coking point of the coal do not seem to have any direct correlation with usefulness in the generator except that there seem to be some indications that a coal that cokes quickly is rather more advantageous than one that remains plastic through a greater temperature range.

One of the most important characteristics is that the coal shall retain its shape and not decrepitate on heating, and a further point is that a coal which is physically strong and resists handling without undue breakage will give far better results than one that breaks easily. This is due to the fact that all fines must be removed or else the generator results will suffer.

Operating Results

We have outlined above the methods that have been developed to permit the successful use of bituminous coal. When we come to consider the results that have been obtained with the use of bituminous coal in the manufacture of carburetted water gas we have to bear in mind that the almost universal use of the blow run has a very direct effect on the fuel and oil efficiency results. This will be evident when we consider that to manufacture 1000 cu. ft. of 335 B.t.u. blue gas requires about 38 lbs. of fuel while 1000 cu. ft. of 150 B.t.u. blow run gas will only require about 18 lbs. of fuel. When we increase the amount of blow run gas used we will decrease the fuel per M. in our finished carburetted water gas, will increase the capacity per set day, and will also increase the oil required to manufacture any specified heating value.

It is well known that the gas oils in use today vary considerably in the enriching efficiency that can be obtained and this variation may

extend from 90,000 B.t.u. per gallon to 110,000 B.t.u. per gallon, so it is evident that the direct comparison of results is not easy.

The subject of calculating the efficiency in the use of oil has received considerable attention in the gas industry for the past several years in an endeavor to secure some methods of determining and evaluating the effect of the blue gas, blow run gas, oil gas and diluents and also, in the case of bituminous coal, the coal gas. The usual practice has been to assume that the oil gave a standard quantity, say 65 to 70 cu. ft. of gas per gallon used, and by subtracting this volume from 1000 and assuming a heating value of 290 to 300 for the blue gas, the heat contributed by the oil gas could be calculated and expressed as B.t.u. per gallon.

It is well known, however, that different oils give varying quantities of gas. This variation in quantity of gas depends upon the temperature of cracking and also apparently upon the concentration of oil gas in the blue gas, so the figures thus obtained were more or less empirical.

Various schemes have been proposed from time to time to calculate the oil gas from the analysis of the finished blue gas by making certain assumptions regarding the composition of the components. Some three years ago Mr. F. Wills, of the Pacific Gas & Electric Company, (32) worked out a method for calculating the percentage of blue gas and oil gas as made in the all oil gas process in use on the Pacific Coast and this method has been modified for use with carburetted water gas in the recent report

TABLE II

COMPARATIVE GAS ANALYSIS—BITUMINOUS COAL AND COKE FUEL

Kind	Blue Gas				Blow Run Gas				Finished Gas			
Fuel	Coke		Coal		Coke		Coal		Coke		Coal	
Illuminants	Nil	.3	1.9	1.1	Nil	Nil	Nil	0.5	9.8	8.6	9.7	9.5
CO	40.9	38.0	33.7	32.1	14.0	16.9	17.8	24.2	29.5	28.9	26.0	23.0
H_2	50.8	46.0	50.3	46.9	4.7	5.0	9.3	10.9	37.6	38.2	32.3	34.3
CH_4	.2	2.1	4.7	4.5	.5	.3	1.7	3.0	11.4	8.9	8.2	9.5
C_2H_6	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0.7	1.0	1.9	1.6
CO_2	3.4	6.9	5.0	5.1	12.9	10.6	8.7	4.5	5.9	5.2	6.0	7.3
O_2	.5	.2	.3	.2	.3	.2	.3	.4	.6	.6	.4	.6
N_2	3.9	6.5	5.0	10.1	67.6	67.0	62.2	56.5	4.5	8.6	15.5	14.2
B.t.u.	300	273	335	317	66	74	105	154	528	525	522	517

of the Water Gas Committee of the American Gas Association(33).

This report also covers certain modifications of this method of calculation for application to carburetted water gas made from bituminous coal when utilizing the blow run and an empirical scheme is devised which permits the calculation of the air, inerts, blue gas, coal gas and oil gas. While some of the assumptions may be open to question and may require modification, it is believed that the use of such formulae may prove of distinct value in analyzing the operation of the apparatus. In this connection, it may be of interest to quote some analyses of the gases produced when operating with bituminous coal as compared with the gases produced when operating with coke. Table II gives analyses of the blue gas, blow run gas and carburetted water gas made from bituminous coal and compares them with corresponding analyses when coke is used as the fuel. These analyses indicate the great economic value of the blow run and clearly indicate why it is necessary to conserve as much of it as possible.

One of the very interesting features of the methods of calculation outlined above is the fact that they indicate that from 55 to 60% of the coal gas available by the ordinary methods of carbonization of bituminous coal are retained and recovered when coal is used in the water gas generator(34).

One of the difficulties involved in the use of these methods is the necessity for accurate sample of both the finished gas, the blow run gas and blue gas, and this introduces quite a difficult problem as it is not easy to take representative samples under the usual operating conditions.

The operating results obtainable today with bituminous coal are the product of steady development and improvement in the technique of operation. When bituminous coal was first used the fuel was usually 40 lbs. per 1000(35), a large amount of which was blown over and had to be removed from the fixing vessels and the capacity was about 50% of the normal capacity. With the introduction of better methods of sizing the coal and removing the fines the fuel dropped to about 36 lbs. and the capacity came up to about 60%, while with the introduction of the pier the fuel dropped to below 30 lbs. and the capacity came up to about 90%. During the last year further experience in the use of pier, better selection and sizing of the

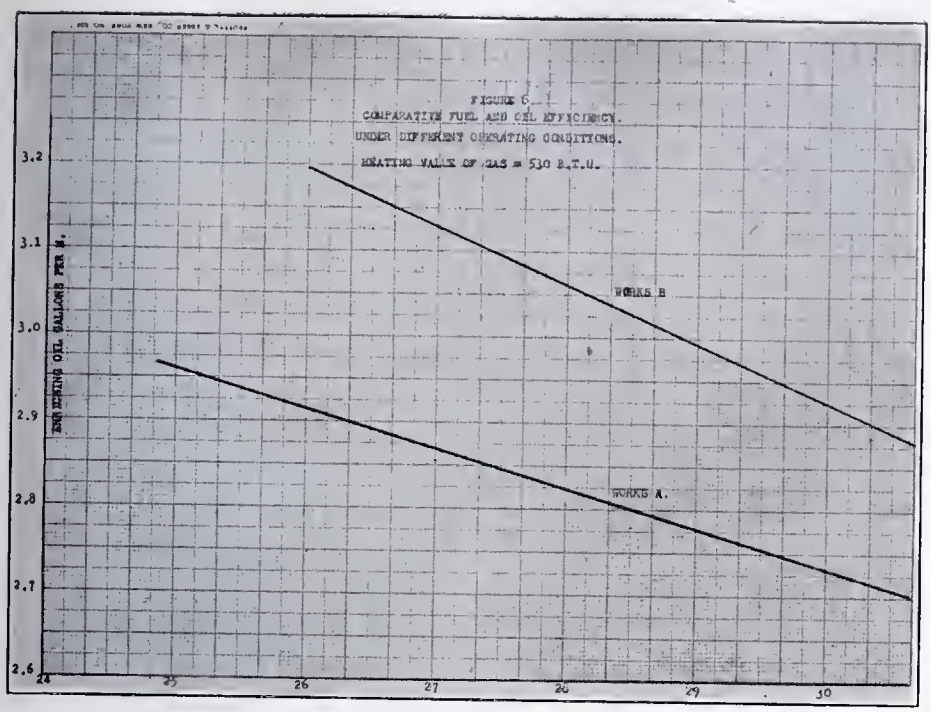

FIG. 6. COMPARATIVE FUEL AND OIL EFFICIENCY

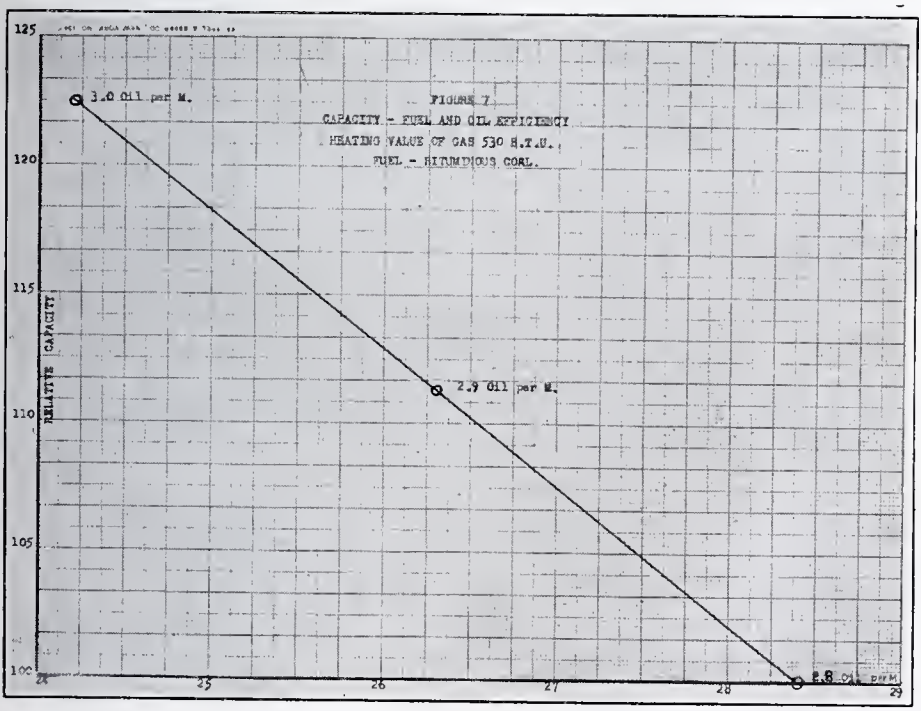

FIG. 7. CAPACITY FUEL AND OIL EFFICIENCY

coal and a better understanding of the operating details have permitted the securing of operating results such as those shown in Fig. 6, together with a capacity approximating that obtained with coke.

The results are based on the production of 530 B.T.U. gas and indicate very clearly the effect of the use of varying amounts of blow run on the apparent fuel and oil efficiencies.

The figures quoted are not test figures, but are averages extending over several months of operation. The difference between the results of Plant A. and Plant B. is purely a question of the character of the fuel and the nature of the oil used. It is believed that both plants are operating with equal efficiency, taking into consideration the raw materials available.

Effect of Blow Run on Capacity

The effect of this variation of fuel and oil efficiency in the capacity can be shown as in Fig. 7, which shows the change in capacity with the variation of the oil and fuel results when making 530 B.t.u. gas.

It is possible with such data to select the optimum operating conditions for any plant having regard to the local requirements of capacity and the available fuel and oil supplies.

It would appear that the use of bituminous coal admits of somewhat greater flexibility in operation than with coke.

Table III gives a comparison of the detailed operating conditions of a plant when using coke and when using bituminous coal.

The reduction in the air to the generator and the increase in the steam are the more noticeable variations in the operating conditions.

Table III

Comparative Operating Condition
Coke and Bituminous Coal Generator 9′0″ Intense Diameter

	Coke	Bituminous Coal
Cycle Seconds	282	228
Blow, % of Cycle	25	33
Blow Run	None	3
Steam Run	75	61
Purge Seconds	None	30 — 37
Down Run, % of Steam Run	50	40
Generator Air Cu. Ft. per Minute	11,000	6,500
Steam Av. Pounds per Minute	165	180

THERMAL EFFICIENCY

When we consider that with the use of coke 30 lbs. of fuel per 1000 is considered a satisfactory operating requirement, we are led to inquire why it has been possible to reduce the fuel with bituminous coal to say 25 lbs. per 1000.

When we consider the comparative heat balances using coal and coke as set forth in Table IV the effect of the higher heating value of the bituminous coal is apparent.

The other feature of the heat balance that deserves attention is the fact that with bituminous coal we require less air per 1000 ft. of gas made, so that this reduces the loss of heat from the fuel bed as sensible heat in the blast products and therefore decreases the amount of steam that may be recovered in waste heat boilers. The recovered steam is also further reduced by the use of back run or Chrisman down run.

It will be noted that the heat losses are relatively small and we cannot expect to make any very large reductions with our present apparatus. When we consider that the theoretical requirements in the process are approximately 12 lbs. of carbon per 1000 to form blue gas which would be equivalent to about 14 lbs. of bituminous coal and 5 lbs. of

TABLE IV

COMPARATIVE HEAT BALANCE

BITUMINOUS COAL AND COKE HEATING VALUE OF GAS=530 B.T.U.

Fuel	Coke	Bituminous Coal
Heat of Combustion of Generator Fuel 30.8 lbs. @ 12,770 B.t.u.	393,000	
27.0 lbs. @ 14,200 B.t.u.		383,000
Heat of Combustion of Gas Oil, 2.5 g. @ 140,000 B.t.u.	350,000	
2.86 g. @ 140,000 B.t.u.		400,000
Total Heat in Steam, 35 lbs. @ 1160 B.t.u.	40,800	46,500
Total Input	783,800	829,500
Heat of Combustion of Illuminating Gas	530,000	530,000
Heat of Combustion of Tar	64,000	77,000
Sensible Heat Illuminating Gas Tar & Steam	55,900	71,800
Sensible & Latent Heat of Blast Products	34,200	44,800
Recovered in Waste Heat Boiler	29,000	22,400
Heat of Combustion of Carbon in Clinker	14,300	11,300
Radiation and Convection	27,800	27,800
Heat Unaccounted For	28,600	44,400
	783,800	829,500

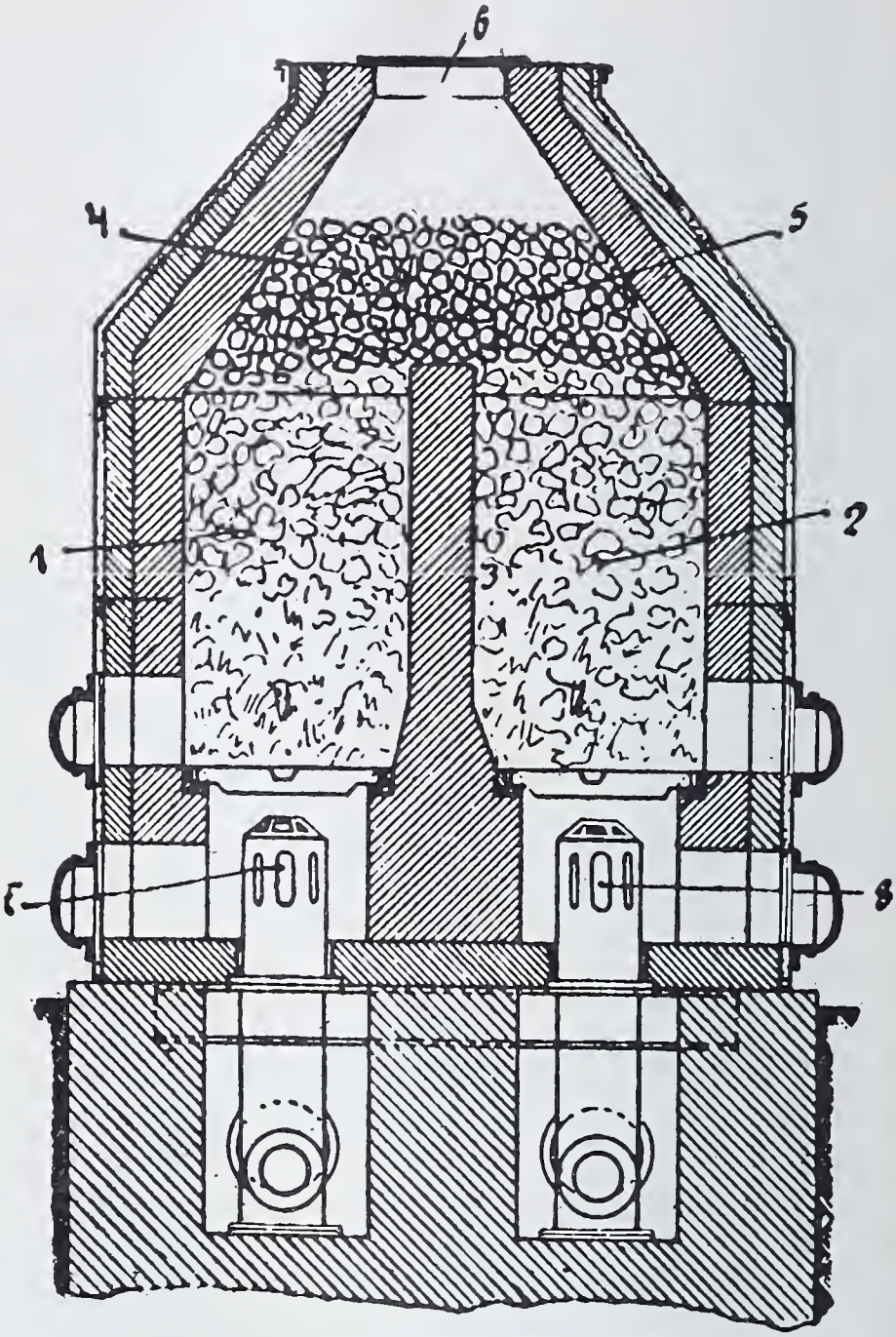

Fig. 8. Dellwik-Fleischer Process

fuel will require to furnish the heat necessary to carry on the reaction it is evident that with the use of bituminous coal in our modern water gas generators we are operating at a relatively high heat efficiency, so we may be led to inquire how this use of bituminous coal compares with the systems of so-called complete carbonization about which much has been heard in recent years.

Complete Gasification

While we in America have given the greatest amount of attention to the use of bituminous coal in the water gas generator, abroad and to some extent in this country work has been going on during the past ten years in developing plants that will deliver as the products of gasification, gas and clinker.

One of the first processes for complete gasification put into practical operation was the Dellwik-Fleischer(36), Fig. 8. This plant comprises a producer divided into two zones, the lower one being filled with incandescent coke, the upper containing the soft coal to be coked by the sensible heat of the water gas. The lower portion of the generator is divided in half by a vertical partition. The chamber on each side of the partition is provided at the bottom with steam and air jets as well as outlets for blast gases. During the blow the air enters at the bottom of the generator on one side of the partition, passes up through the coke, over the top of the partition and down through the coke on the other side, the waste gases thereupon passing out through the waste gas valves. During the run steam is admitted simultaneously on both sides of the partition at the bottom of the generator. The water gas formed by steam passing up through the hot coke is also led through the coal contained in the upper part of the generator and out through a valve in the top of the generator. Since the sensible heat of the water gas was insufficient to coke the coal, a certain amount of air must also be admitted during the run. The quality of the gas depends upon the kind of fuel used and the method of plant operation. The calorific power of the gas may vary from 280 to 390 B.T.U. per cu. ft.

In chronological order, probably the next important complete gasification process is the Rincker-Wolter(37), Fig. 9. The chief feature of this apparatus is the utilization of twin generators. While the first generator contains the coke from freshly carbonized coal, the second contains a fresh charge of this coal. The heat stored up in the generator together with the heat in the coke bed upon which it rests is suffi-

cient to carry on distillation of the coal while the first generator is being blown. During the run in generator number one, the water gas produced passes over and down through the coal in number two, thus carrying on the distillation further. When the coal in number two is reduced to coke a charge is added to number one and the process repeated but now in the opposite direction.

The Simon-Carves Company states that the above process produces 56,000 to 60,000 cu. ft. of 350-360 B.t.u. gas per long ton of coal which corresponds to 38-40 lbs. of fuel per M.

A plant for complete gasification which has not been very extensively used is that installed by F. H. Robinson(38) at Harrogate, England. It consists of a water gas generator built across the ends of a bench containing eight horizontal retorts. The coal is carbonized in the horizontal retorts and then pushed into the generator. During the blow, the blast gas is passed through checker chambers surrounding the retort, while during the run the water gas is passed through the retorts. Depending upon the mode of operating it was found that a 425 B.t.u. gas could be produced with consumption of 54.5 pounds of

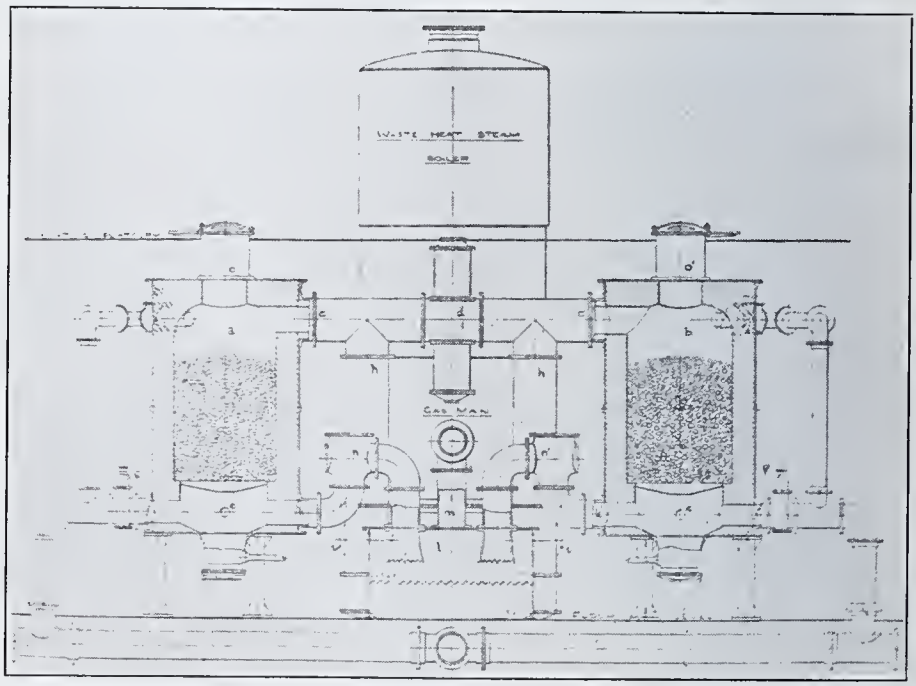

FIG. 9. RINCKER-WOLTER PROCESS

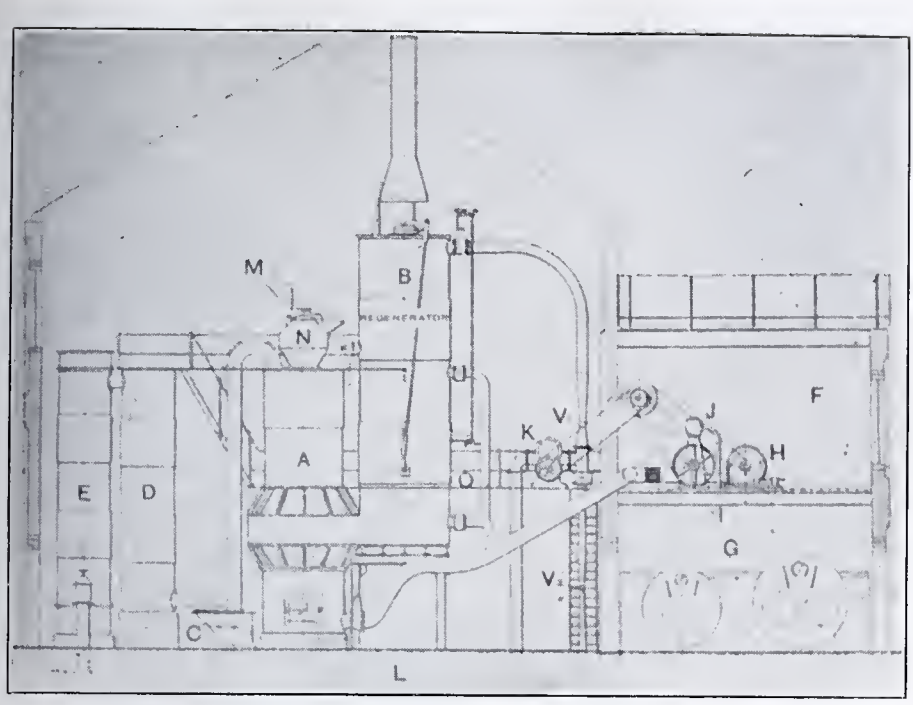

FIG. 10. TRAVERS-CLARK PROCESS APPARATUS

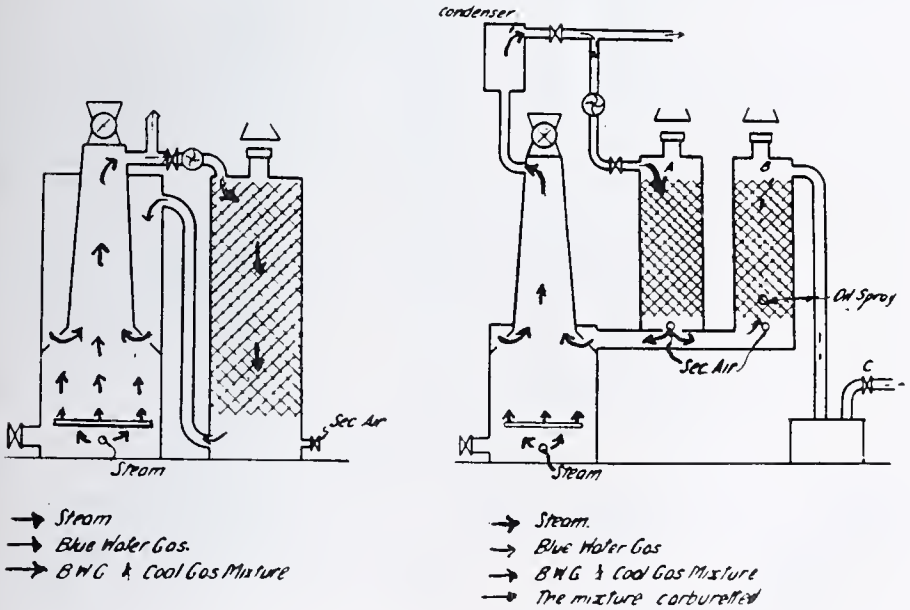

FIG. 11. TRAVERS-CLARK PROCESS DIAGRAM

fuel per M., a 344 B.t.u. gas using 40.7 lbs. of fuel per M. and a 280 B.t.u. gas from 31.8 lbs. of fuel per M. When making a 425 B.t.u. gas the overall efficiency was 66.5%.

One of the more important complete gasification processes now in practical use is the Travers-Clark(39), Figs. 10 and 11. This apparatus consists of two chambers, a generator and regenerator for conserving the heat. The charge of fuel in the generator may be divided into two zones, the lower zone containing the incandescent coke and the upper containing the coal to be carbonized. During the blow, air passes from bottom of the grates up through the coke, passing from the generator to regenerator through outlets situated at the junction of the coke and coal zones. The blast products are completely burned in the regenerator by means of secondary air. During the run, the steam passes up through both the coke and coal zones and out the top of the generator. At the same time some of the gas is drawn from the main by means of a circulating engine and recirculated through the set. This is done by forcing the gas down through the regenerator and up through the coal, thus carrying excess heat stored in the former over to carbonize the coal in the latter. During the down run, steam is first preheated in the regenerator.

The operating results have indicated that 45.3 lbs. of coal and .87 gallons of oil were required per M. of 412 B.t.u. gas.

In England the Tully (40), Fig. 12, complete gasification process seems to be the most extensively used at the present. Numerous types of this plant have been built with a view to meeting the particular requirements of a locality.

The simplest type consists only of a generator and wash box. The generator consists of two sections, the retort and the generator proper. The generator comprises the lower portion of the set while retort is in the upper part and is surrounded by checkerbrick. A three-way valve allows the gases to pass from the generator through either the retort or the checkerbrick surrounding it.

The second type differs from the first by the addition of a carburetor which enables any desired calorific quality of gas to be obtained by the use of oil.

The third type consists of a twin retort plant which is blown in parallel and alternately steamed in series, first through one retort then through the other.

A more recent type has resulted from a joint invention of Mr. Tully and Mr. O. E. Yeo(41). The plant consists of a retort superimposed on a generator and embodied in the one shell, a carburetor and a waste heat boiler. During the blow gases leave the generator by way of nostrils situated at the base of the retort and pass through checkerbrick surrounding the retort. Secondary air is also admitted at the point where the gases enter the checkerbrick. From there these gases pass into the waste heat boiler. During

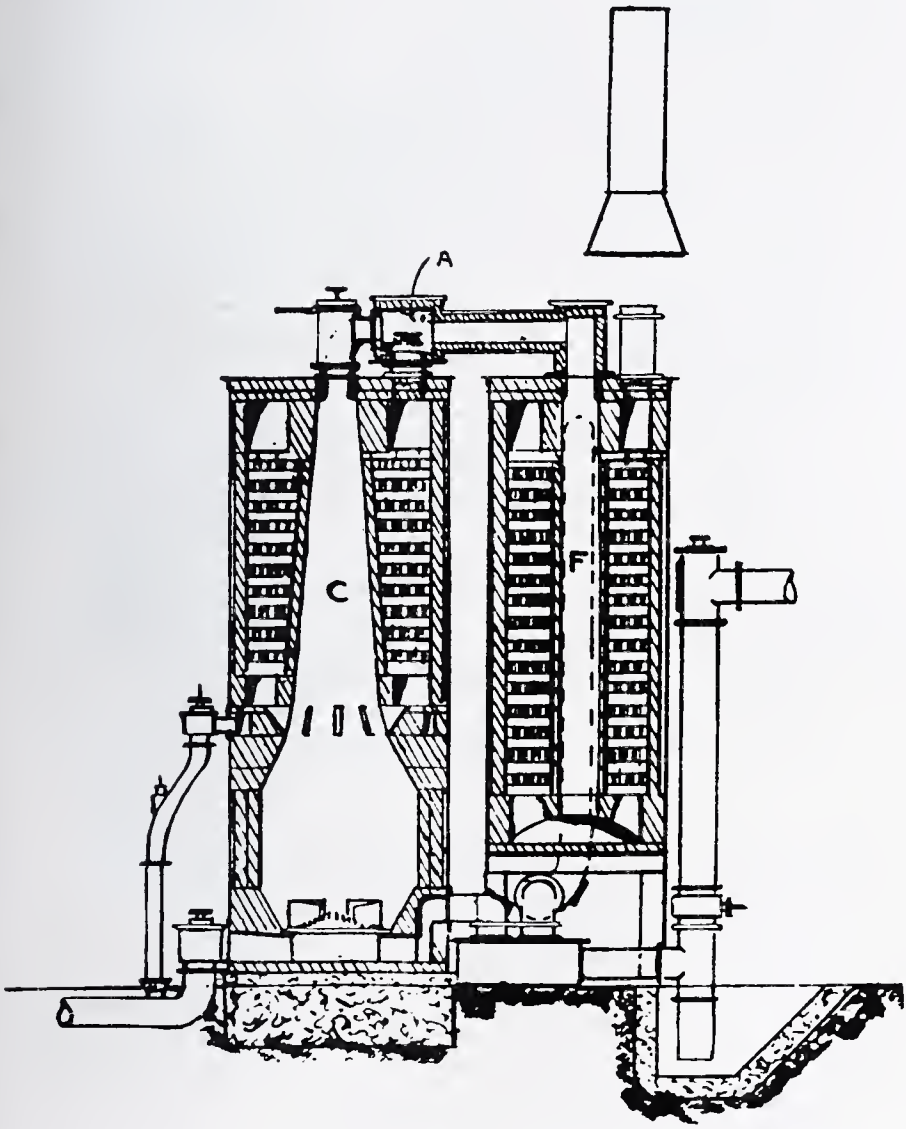

Fig. 12. Tully Process

the blow any rich coal gas formed is drawn off into the foul main through a special outlet. During the run about three-quarters of the water gas passes up through the retort and becomes enriched with coal gas. The remaining 25% may be passed through the nostrils in the carburetor where it is enriched with oil gas. A special design of the Tully-Yeo plant possesses a triple generator system. In this way, one unit may be blown while the other two are being steamed. This allows a continuous passage of hot gases through the waste heat boiler.

The following results were obtained from some test on a Tully plant at Halifax, England (1925) (42):

Maximum rate of generator was found to be 1,500,000 cu. ft. per day of a gas slightly under 340 B.t.u. On the other hand, the richest possible gas made gave 416 B.t.u. per cu. ft.

The results of a 24 hour test showed a consumption of 41.5 lbs. of fuel per M. giving a gas of 340.5 B.t.u.

Some results obtained with a Tully complete gasification plant in France:

Type of Coal	Raeder-flamm (Saar)	Luis-anthal (Saar)	Mathilde (Silesia)	Sutton Cables
Volatile Matter	32.27	36.78	31.82	32.6
Ash	11.60	9.50	7.30	4.2
Fixed Carbon	52.20	49.50	55.80	63.1
Lbs. Fuel per M	48	50	50	...
B.t.u.	359.5	354	365	355.5

Type of Coal	Marles	Marles	Bruay	Marles 75% Coke 25%	Coke
Volatile Matter	35.48	29.67	32.35	.....	.....
Ash	8.30	7.6	8.40	.....	.....
Fixed Carbon	51.3	59.7	57.0	.....	.....
Lbs. Fuel per M	51.4	49	52	48	.....
B.t.u.	356	351	361	326	303

Tar came to 4.8%, Sp. Gr. 1.085

Efficiency of process was 55.6%.

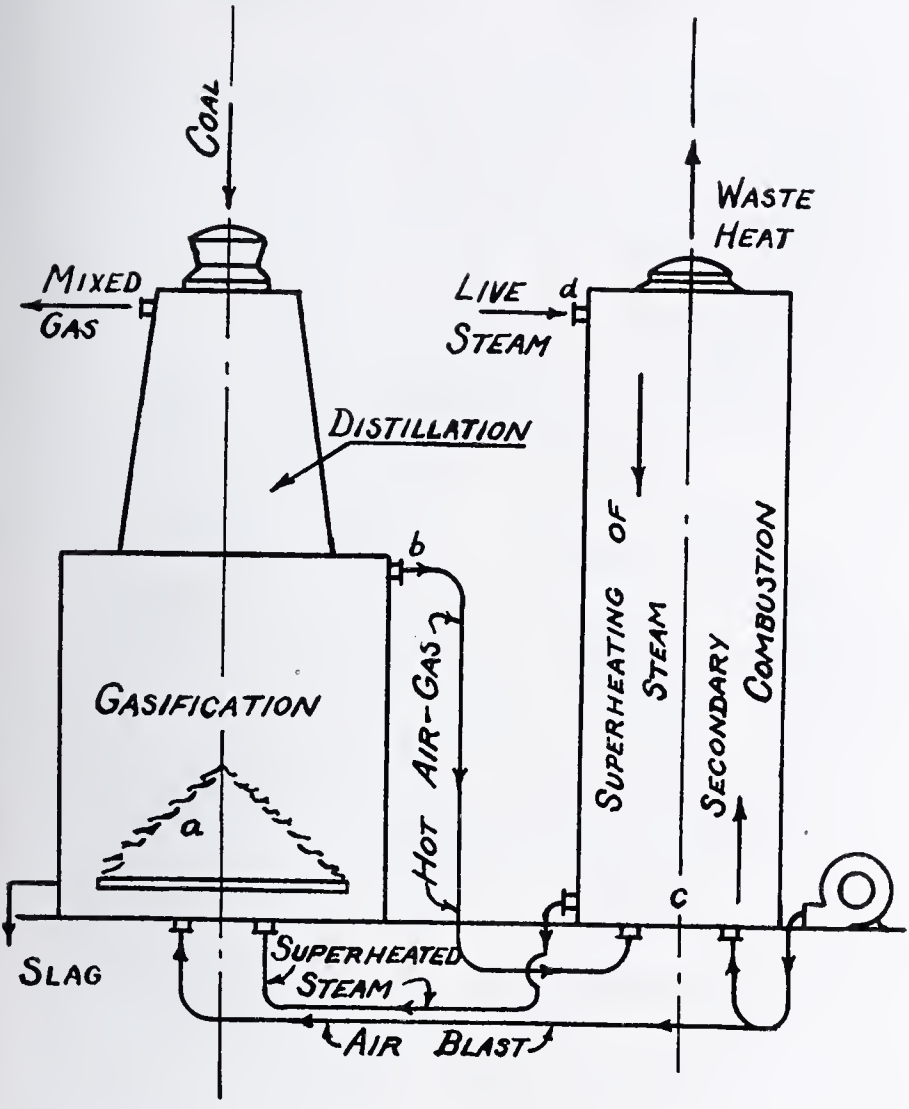

Fig. 13. Strache Process

The Strache(43), Fig. 13, complete gasification process has found rather extensive application in Germany and other European countries.

A retort or coking chamber in the form of an inverted frustum of a cone extends down into the generator. During the blow the blast gas is forced to pass up and around the retort and thence into the regenerator. A by-pass or bleeder allows the coal gas to pass off into the mains during the above operation. During the run

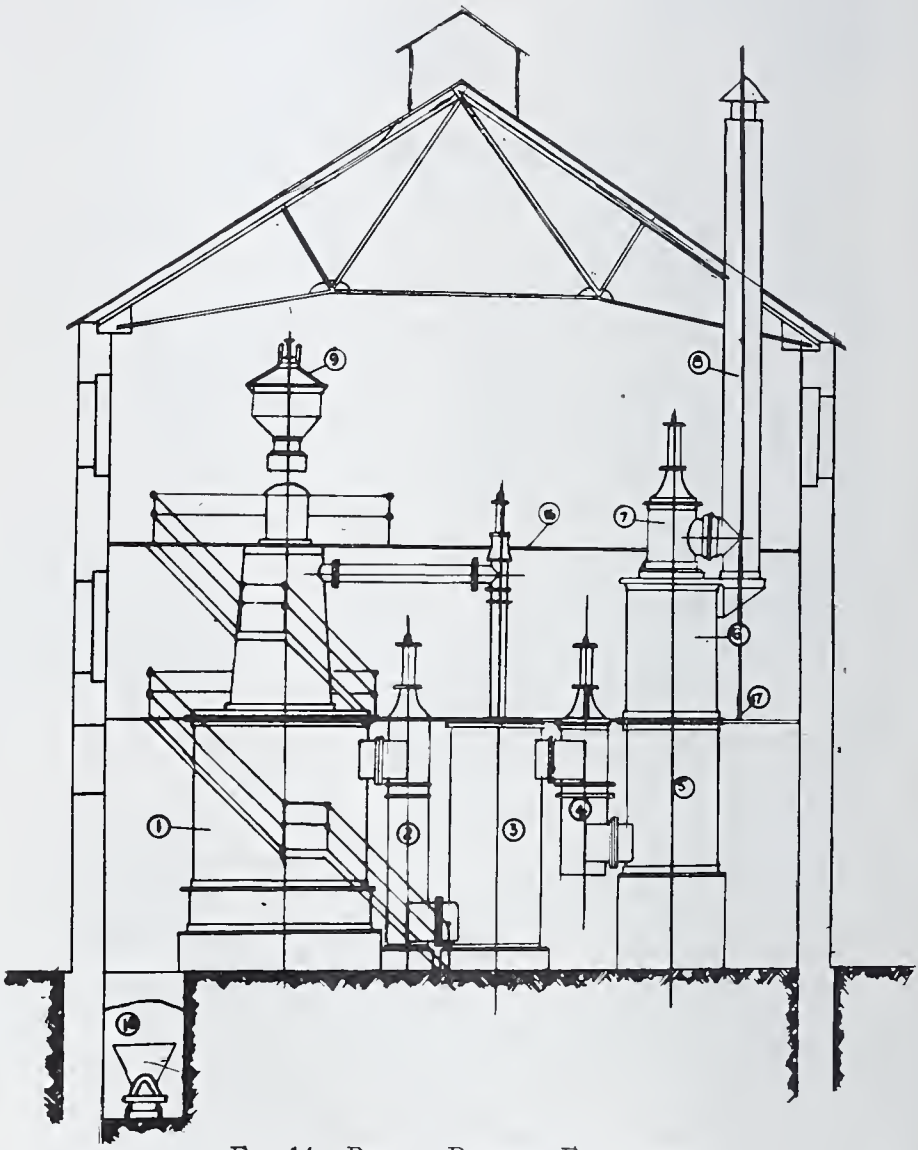

Fig. 14. Breisig Process, Elevation

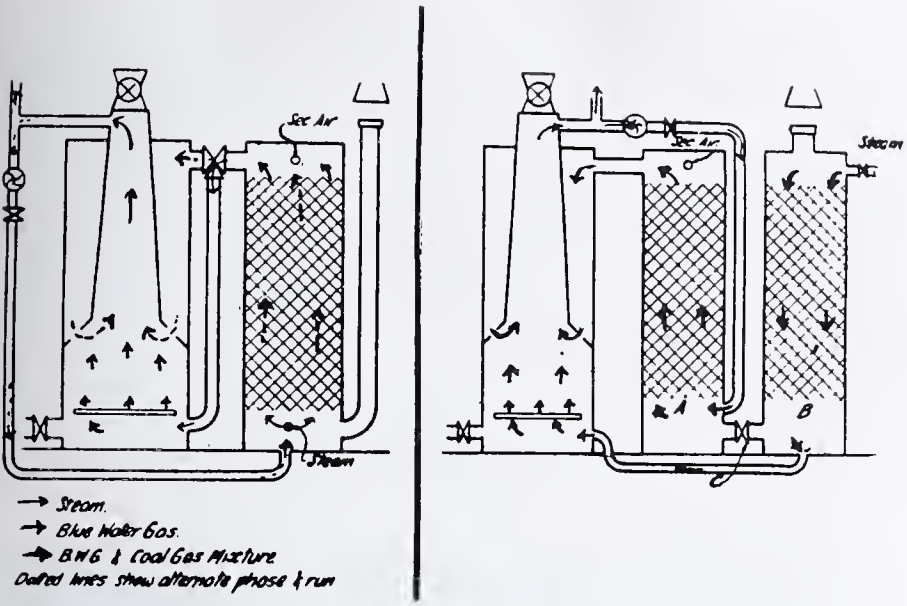

FIG. 15. BREISIG PROCESS, DIAGRAM

steam is passed into the regenerator where it is first superheated, then enters the generator below the grate, thence passing it through the coke and coal in the retort. The mixture of water gas and coal gas is then led off at the top of the retort.

The following figures are some results obtained with the Strache double-gas process.

Fuel	Upper Silesia Coal.	68% Coal 32 " Lignite	Coal
Lbs. per M.	49.1	56.2	42.4
B.t.u.	374.6	349.4	380.9

The apparatus for the Breisig complete gasification process, Fig. 14 and 15, consists essentially of a generator, a superheater and a supplementary superheater.

The middle part of the generator is connected to the bottom of the superheater by means of a valve. The top of the superheater is connected in turn to the bottom of the second superheater by means of the valve. The generator consists of two sections. The lower contains the incandescent coke and is the water gas generator proper. The upper portion contains the freshly charged coal in the process of being carbonized. The top of the generator is also connected to the top of the superheater. It should be noted that the bases of the three

chambers are connected to each other and to the blower by means of pipes below the generator floor and not shown in the diagram.

The method of operation is as follows: During the blow, air is forced into the bottom of the generator and up through the bed of coke. The blast products pass into the superheater through the intermediate valve and thence into the secondary superheater by means of the intermediate valve. Secondary air is supplied to both superheaters through the base of each. All the combustion products leave the set by way of the stack.

During the run steam enters the system at the top of the secondary superheater, passes down through the chamber and out the base by way of what was the secondary air inlet during the blow. The steam

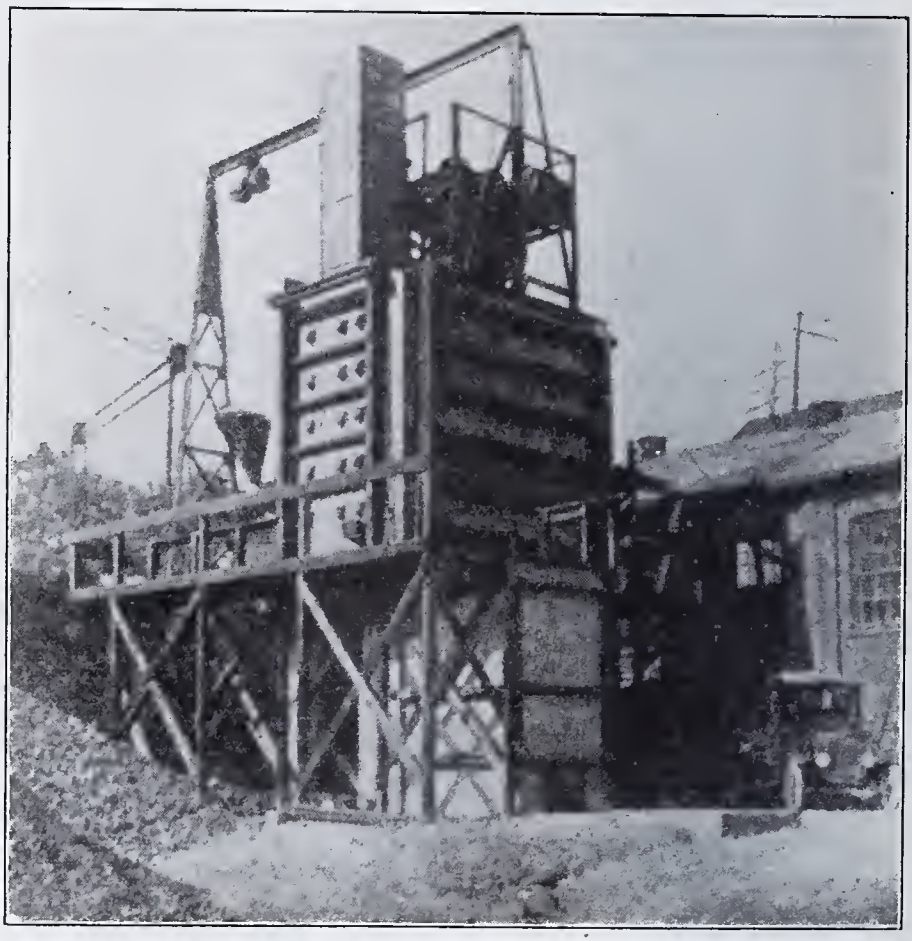

FIG. 16. MCDONALD PROCESS

then passes along the connecting pipe and enters the base of the generator where it passes up through the bed of incandescent coke and produces water gas. The water gas continues up through the coal in the upper section of the generator, passing out the top of the same and into the top of the first superheater. The gas which is now a mixture of water and coal gas is led down through the superheater with the object of cracking the particles of oil and tar present in the coal gas. From the superheater this specially treated gas passes into the intermediate valve, where it is divided into two portions. One portion is passed on

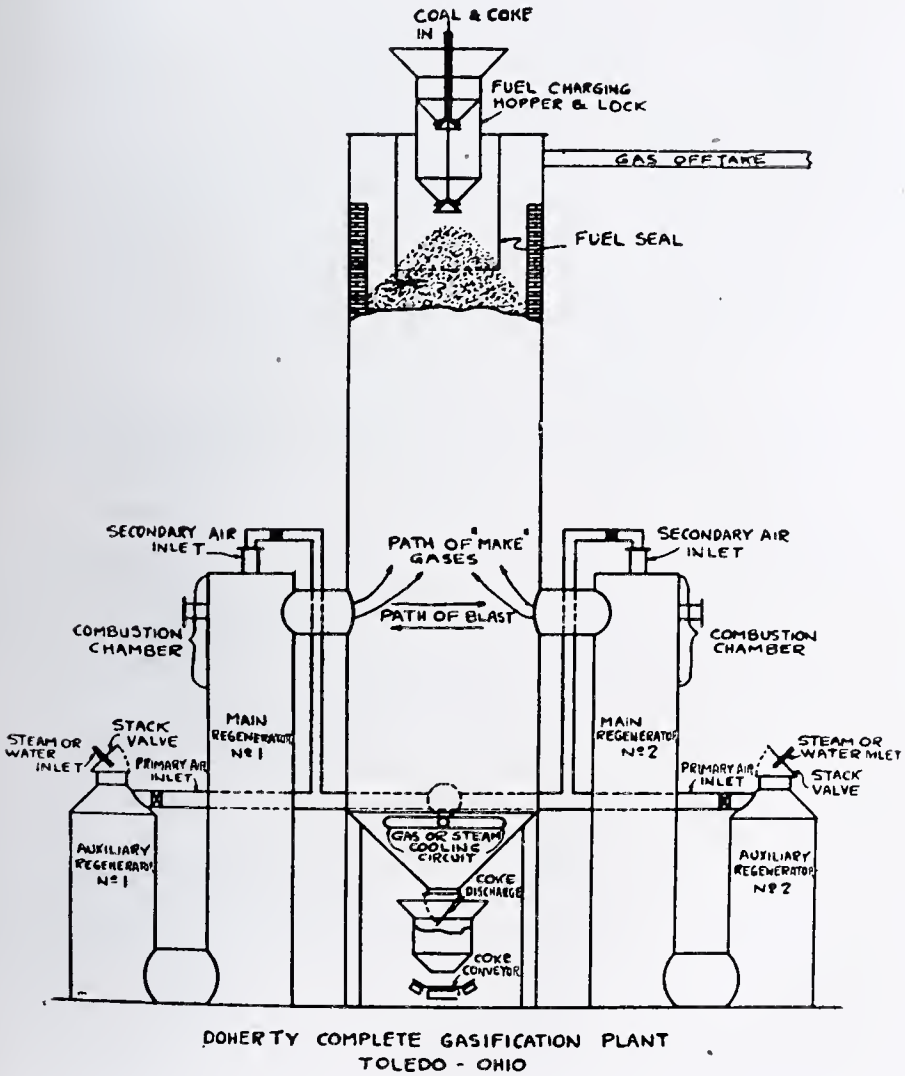

FIG. 17. DOHERTY PROCESS

to the relief holder, while the other portion enters the generator by way of the central connection and recirculates up through the coal in conjunction with the water gas. By this procedure a quantity of heat produced during blasting is utilized in carbonizing the coal.

The following figures are some of the claims for the Bresig process given by the Kreisa company:

B.t.u. per cu. ft. Gas.	Lbs. of Fuel per M. Gross.	Lbs. of Coke recovered.	Net lbs. of Fuel per M.
562	109.5	63.4	46.1
427	44.6	....	44.6
528	93.2	35.5	57.7
472	69.3	15.8	53.5
495	87.9	37.9	50.0

In 1922, R. G. Porter, Chairman of the A. G. A. Committee on the Complete Gasification of Coal Section mentioned two processes installed in this country. These were the J. U. McDonald and the Doherty. The McDonald(44) process, Fig. 16, was installed at Valparaiso, Indiana. Briefly, the method of operation is as follows: The coal is fed into vertical retorts whose temperature is maintained by external heating. The steam is passed into the top of the retort down over the carbonizing coal and through the incandescent coke in the bottom of the apparatus. The tar and other volatile matter is thereby gasified by the bed of hot carbon. No operating results are given.

A Doherty(45), Fig. 17, complete gasification plant was installed in Toledo, Ohio. The gas making machine may be described as a tall shaft, 100 to 200 ft. high, lined with firebrick and provided with suitable openings for gas offtakes, air and steam inlets. The coal is charged at the top and allowed to settle gradually to the bottom where a portion is drawn off as ash and coke. The coke is separated from the ash and added to the generator along with fresh fuel. In such a high generator, the tar and oils are being constantly condensed in the upper part and returned to the hot coke where they are cracked and changed into permanent gases. The gasification process consists in alternately blasting the lower fuel zone with preheated air and then with the superheated steam. The blast products are passed into a regenerator. The steam is produced by spraying hot water on to the hot regenerator bricks. It then passes through the coke giving water gas which travels up through the carbonizing coal and leaves the top of the generator at

about a temperature of 500° F. The gas produced has a heating value of 300 to 325 B.t.u. per cu. ft.

Comparative Heat Balances

When we come to consider the approximate heat balances of these systems of complete carbonization as compared with those secured in the water gas generator as shown in Table V we find that they have very little theoretical advantage from the heat efficiency standpoint over our existing apparatus and that their principal argument is that they can produce an uncarburetted gas of from 10 to 20 B.t.u. higher heating value than we can secure from our existing apparatus, and therefore they should require slightly less oil per thousand. However, the best figures that we have been able to obtain appear to indicate that the capacity secured in a given size apparatus is considerably less than in our existing carburetted water gas sets, so that we would have to consider the slight increase in oil as against the increased installation cost. It would seem at the present time that in view of the fact that we can utilize the bituminous coal in the Pier process in our existing

Table V

Comparative Heat Balance—Utilization of Bituminous Coal in Carburetted Water Gas Process and Complete Gassification

	Carburetted Water Gas	Complete Gasification
Heat of Combustion of Generator Fuel 339 lbs. @ 14,200 B.t.u.	481,380	
453 lbs. @ 14,200 B.t.u.		580,360
Heat of Combustion of Oil 1.15 gals. @ 140,000 B.t.u.	162,000	
.87 gals. @ 140,000 B.t.u.		121,700
Total Heat in Steam 40 lbs. @ 1160 B.t.u.	46,500	
34 lbs. @ 1160 B.t.u.		39,068
Total Heat Input	689,880	741,128
Heat of Combustion of Illuminating Gas	412,000	412,000
Heat of Combustion of Tar	31,050	23,400
Sensible Heat Illuminating Gas, Tar & Excess Steam	69,600	68,000
Sensible & Latent Heat of Blast Products	56,200	96,800
Heat Recovered in Waste Heat Boiler	28,100	None
Heat Loss in Ash	14,180	16,194
Radiation and Convection	32,200	39,700
Heat Unaccounted For	46,550	85,038
	689,880	741,128

apparatus so successfully, at least with the present price of oil there is not sufficient saving to warrant the cost of installing new apparatus that will probably be considerably more expensive per unit of capacity obtained.

However, it is claimed that certain of these complete gasification processes will handle coal containing small sizes and even considerable slack, and if this proves to be true when they are applied to American practice the saving in the ability to utilize this small size coal may be sufficient to overcome the higher investment cost and make them economical.

This same situation may arise should gas oil double in price, under which condition the saving in oil might overcome the existing increased capital charges. However, at the present time it is purely a question of economics that can be settled only when all the factors that make up the local situation are taken into consideration.

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A REVOLUTIONARY IMPROVEMENT IN GAS PRODUCTION

By C. J. Ramsburg

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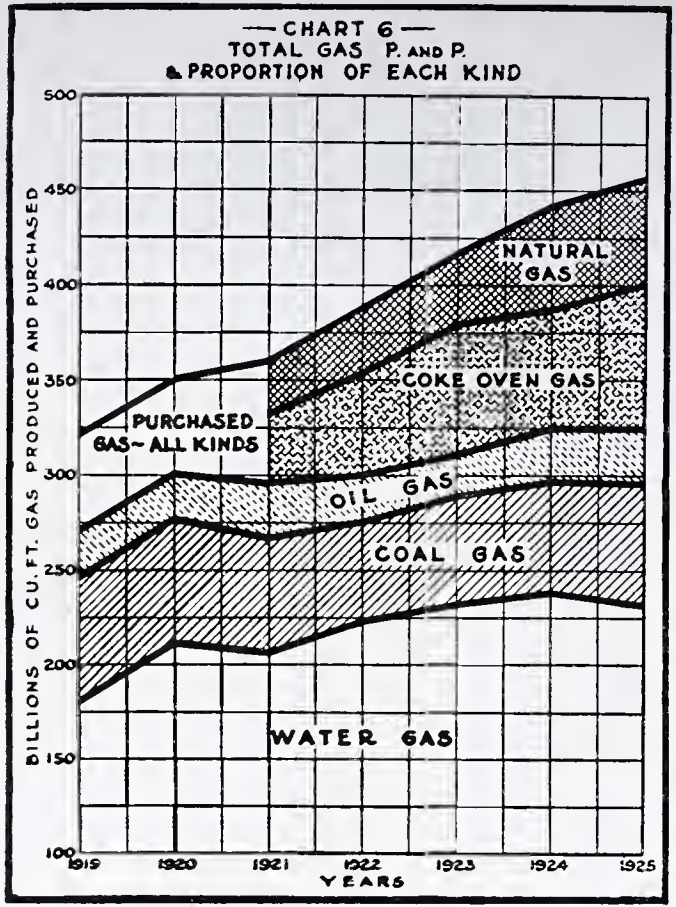
With the growth of the electric industry, popular imagination has been stimulated toward acceptance of the thought that it should only be a question of time until the magic wand would wave all heat employed, as well as power and light, into that type of energy. Fortunately, mature consideration readily dispels the glamour of that idea and proves its intrinsic fallacy.

It can easily be demonstrated that by modern methods heat is delivered in the form of gas with much greater efficiency than in the form of electricity, and we are of the opinion that the Gas Industry is about to witness a development that will make its efficiency in this respect even more striking.

From one pound of coal, containing 14,000 B.t.u., the most modern type of electric generating station delivers to your home or industrial plant 2,250 B.t.u., or an overall efficiency of 16%. A modern gas plant, operating with mixed coal gas and producing blue gas from the resulting coke, crediting only the fuel value of the by-products, can deliver 9,000 B.t.u. from the pound of coal, or an overall efficiency of over 60%. It therefore follows that with a given amount of heat to be secured, only one-fourth the amount of coal is necessary when supplying the heat in the form of gas than when the same amount of heat is secured from the electric plant. Please remember that I am talking about heat and not *power*.

Under *heat* for domestic use should be included house-heating and cooking. Modern life is built on comfort. We prefer to purchase comfort rather than troublesome economy. For this reason, gas house-heating with thermostat control will inevitably supplant the present coal and coke furnace with its constant necessity for attention and with its accompanying space occupation, dirt and other discomforts. Even though the cost of gas heating be greater, the demand for comfort is insistent.

Gas will also be an important factor in refrigeration, and later may even be used in summer for air conditioning in the home. Any



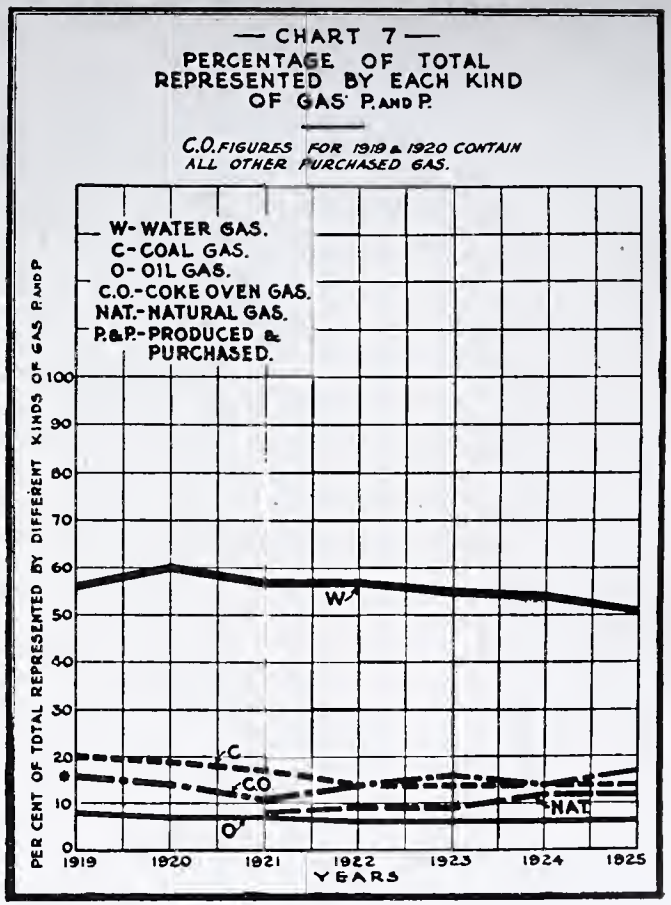


FIG. 1. RELATIVE QUANTITIES OF GAS SUPPLIED BY PUBLIC UTILITIES IN 1925

improvement in methods of gas production involving higher efficiencies, lower labor costs, lower costs of plants, increasing the output and capacities and efficiencies of existing plants, and making possible the easy availability of peak load gas at lower cost, is an important and revolutionary improvement.

We are confident that blue gas is going to become an important substance in the future development of synthetic chemical products, perhaps so far reaching as to effect many industrial changes of great magnitude.

Commercially, the important gases are coke oven gas, carburetted water gas, blue gas, oil gas and producer gas. Gas supplied by public utilities throughout the country today is predominantly carburetted water gas. Gas used in industrial processes is either city gas or natural gas when purchased, or coke oven gas, blue gas or producer gas when secured from auxiliary plants.

Fig. 1, secured through the courtesy of the American Gas Association, shows the relative quantities of gas supplied by public utilities in the United States in the year 1925. This figure is divided into Chart No. 6 and Chart No. 7. On Chart No. 7 it will be noted that there has been a slight falling off since 1920 in the relative amount of water gas produced, but that the quantity of water gas produced as shown on Chart No. 6 has increased practically twenty billion cubic feet in that time, and it is manifest that carburetted water gas is still a very important factor in the gas situation.

The purpose of this paper is to set forth a consummation of a desire and need on the part of the gas industry, and for industry in general, for a process which would produce uninterruptedly carburetted water gas or blue gas from coke, bituminous coal or anthracite coal, while *preserving a high capacity* in gas of good quality.

Before going into this matter I would like to point out for the benefit of those not in contact with water gas operation, that in the production of this gas approximately 28 lbs. of fuel is used per M. cubic feet of carburetted water gas of 530 B.t.u. and 35 lbs. of fuel per M. cu. ft. of blue uncarburetted gas of 290 B.t.u. Since the operation involves the gasification of the fixed carbon by alternately blasting and steaming, the ash remains in the generator, and due to the necessary high temperatures employed and the narrow zone of such high temperatures, this ash may be fluxed to the base of the

generator. In an eleven foot generator, producing during twenty-four hours three million cubic feet of blue gas, using a coke fuel containing 10% of ash, the amount of clinker formed would be over five tons. It is customary to remove this clinker periodically, two to three times a day. It requires no technical appreciation to see at once that such a process has the following disadvantages:

1. A change in fire depth each succeeding hour as clinker builds up.
2. A change in blast pressure to secure uniform blasting speed.
3. A tendency to channel on account of uneven distribution of air and steam.
4. A loss in time while the generator is being clinkered amounting to from 10% to 20% of the gas making period.
5. A loss of fuel consumed by natural draft during the clinkering period while the doors are open.
6. A loss in fuel on account of carbon being removed with the ash.
7. Almost unbelievably hard manual labor, especially in warm climates and under hot weather conditions.
8. Spare apparatus to be placed in operation while clinkering, if uniform production is required.

A new process has been devised, which, by the operation of a mechanical generator base removes, *as formed,* the clinkered ash, thus overcoming at once all of the difficulties enumerated above and enabling the production in equal hourly quantities for weeks, or even months at a time, of high quality gas.

In October, 1925, there was placed in operation at the Water Gas Plant of the Chicago By-Product Coke Company, a subsidiary of The Koppers Company, a water gas generator supplied with a new grate and base, mechanically operated. This has been the subject of many experiments since that time. For several months this machine has been operating with such success and under such conditions that it is felt that we are warranted in disclosing the matter, with the feeling that the problem has been solved.

This invention is the idea of Mr. C. W. Andrews, of Duluth, Minn., and Mr. Herman A. Brassert, of Chicago, worked out in conjunction with Mr. W. B. Chapman, of the Chapman Engineering Company. The construction has been carried out by The Kop-

pers Company through its subsidiaries, The Western Gas Construction Company and the Chicago By-Product Coke Company.

While this generator base and its successful operation are of great importance, one other process in operation must also be taken care of in order to secure continuous and uninterrupted gas production. This problem has also been solved by the invention of the Howard Automatic Charger. This apparatus is the invention of Mr. A. C. Howard, of New York, and Mr. Thos. W. Stone, of The Western Gas Construction Company, and has been in operation at the plant of the Northern Indiana Gas & Electric Company at Fort Wayne, Indiana, for more than a year. While these two processes have not yet been combined and operated in one generator, a generator including both processes is now under construction and is expected to be in operation during February, 1927. It may be said, without fear of adverse comment, that the combination of these two elements is devoid of any possible difficulty. It is believed the achievement is revolutionary in its scope and effect.

Before discussing the details of the self-clinkering generator base and the automatic charger, and the results secured by their use, I would like to review in a brief manner the general developments in water gas operating methods since their inception.

The fundamental principles of carburetted water gas manufacture of today are essentially the same as when Prof. Lowe built the first plant at Phoenixville, Pa., in 1874. Now, as in Prof. Lowe's time, steam is passed through incandescent carbonaceous material such as coke, anthracite or bituminous coal, resulting in blue gas composed of hydrogen and carbon monoxide. Petroleum oil is sprayed into this gas as it passes through a second chamber, or carburetter, and is cracked by the heat into the lighter hydrocarbons, which at lower temperatures are fixed gases or quite volatile liquids. These hydrocarbons are largely ethylene, propylene, benzene, and other unsaturated compounds and are relatively high in heating value. Blue gas thus enriched is termed carburetted water gas and is essentially the same as that produced by Prof. Lowe, both in composition and basic method of manufacture.

The increased knowledge of the equilibra of the reactions involved, advances in information on heat transfer and thermodynamics, the improvement in materials available, the advances in mechanical design—all the fruits of carefully planned and patiently

pursued research—have made possible the construction of water gas machines of exceedingly ingenious design and the operation of them at capacities and efficiencies unthough of not only by Lowe, but by his successors in the gas industry up to a relatively recent day.

From a cumbersome unreliable apparatus operated at low capacities and low efficiencies and then only with extraordinary manual labor, the water gas machine has ultimately evolved into an efficient and reliable apparatus, flexible to the extreme, with entirely automatic operation.

As late as 1898 it was the usual practice to maintain a constant blast pressure drop across the grate and fuel bed, falsely termed "effective pressures." This, of course, meant the use of a constantly decreasing amount of fuel each succeeding hour and a rapid falling off in capacity and efficiency as the clinkering time approached.

The first improvement was to so adjust the blast as to effect the burning of the *same quantity* of fuel each hour. This step naturally was accompanied by increasingly higher blast pressure beneath the grate, which is an important factor in capacity. The result of constantly increasing the blast pressure from clinker to clinker in order to maintain a uniform consumption of fuel opened up a new field of thought and new standards of capacity and efficiency.

It became apparent from the use of a crude measuring device, consisting of a manometer tube placed so as to make use of the stack blast orifice as a crude meter, that great improvements could be secured by measuring accurately the air and steam being delivered to the set. Measuring devices were developed, the results quickly indicating the necessity for greater blast pressures, for definite heat control by means of pyrometers and finally the necessity for hydraulic control of operating valves. With the introduction of the hydraulic control, the automatically operated generator was a natural consequence.

I would like to say, while I have the opportunity, that the working out of the initial problems of air and steam measurement, heat control, hydraulic operation and automatic control was largely the work of Mr. John Hawley Taussig, deceased, of The United Gas

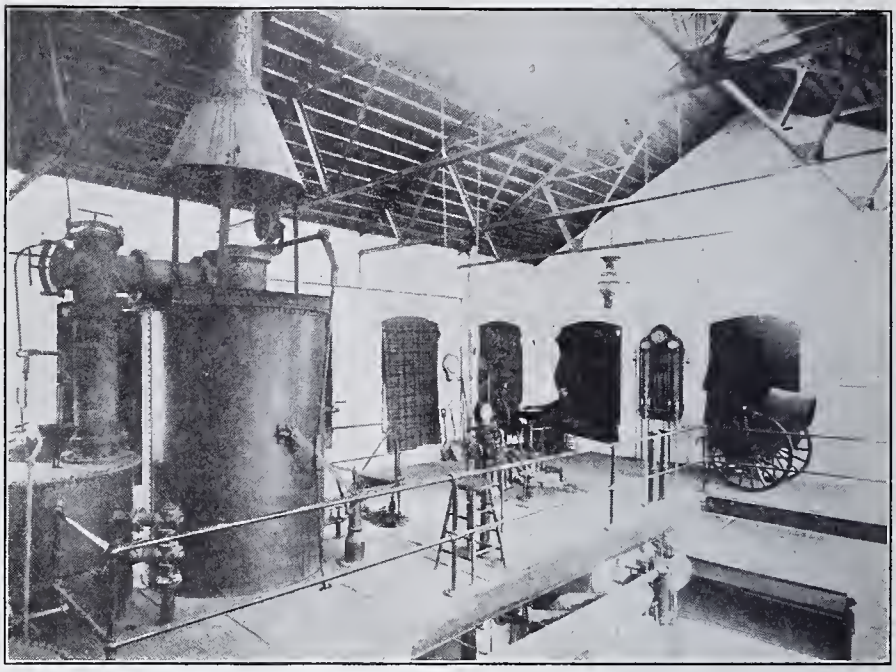


FIG. 2. HAND CONTROLLED WATER GAS SET

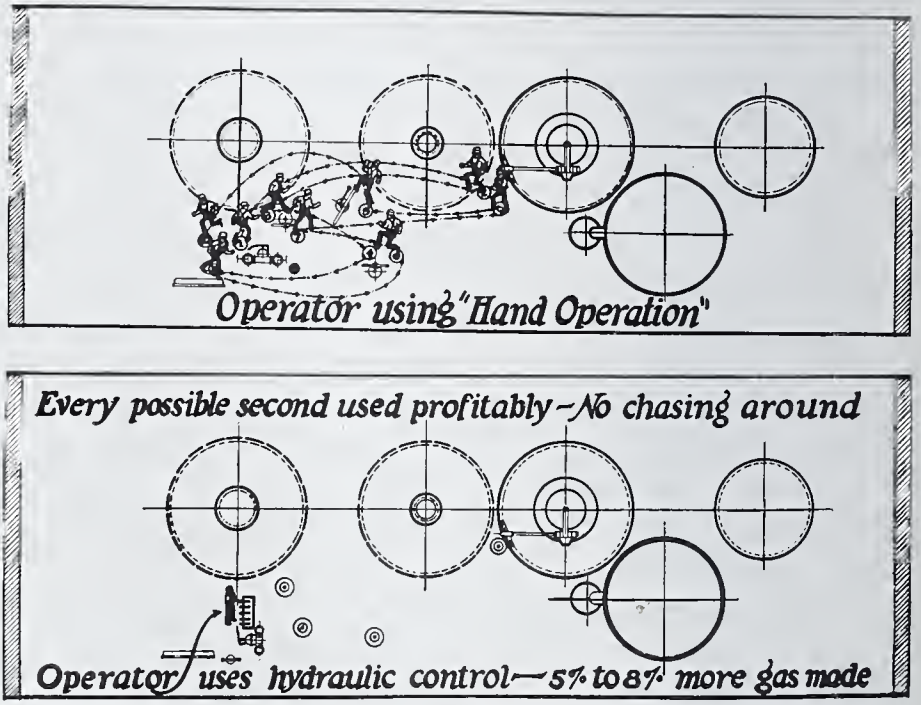

Operator using "Hand Operation"
Every possible second used profitably—No chasing around
Operator uses hydraulic control—5% to 8% more gas made

FIG. 3

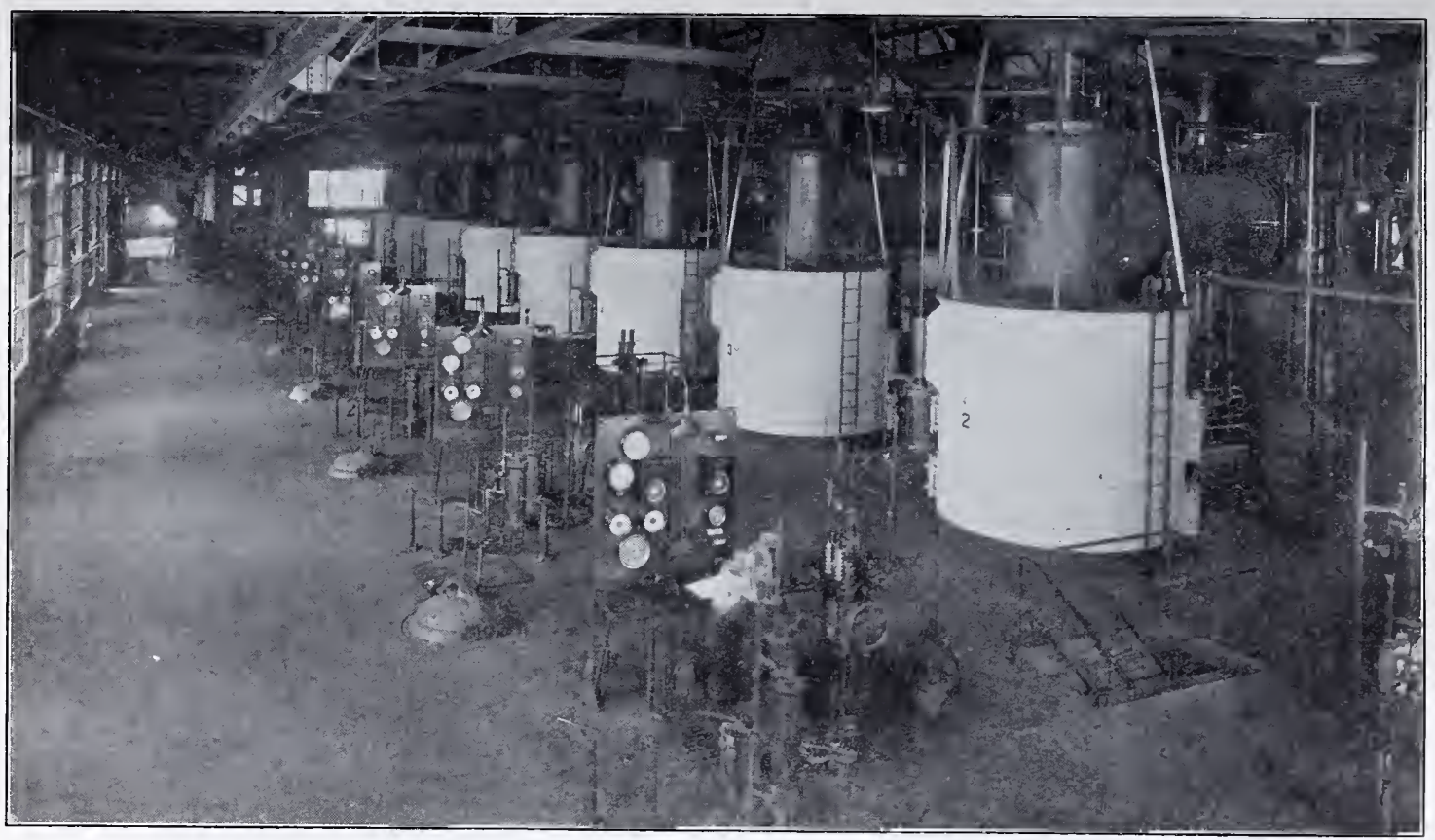


Fig. 4. Operating Floor—Chicago By-Product Coke Company

Improvement Company, of Philadelphia. To him the gas industry is greatly indebted.

Fig. 2 illustrates a hand controlled water gas set, and Fig. 3 represents the path the gas maker traveled at each change of cycle. One gas maker was required for each machine. A long cycle was necessary with a wide variation in fuel bed conditions at different stages of the cycle.

Fig. 4 is the operating floor of the Chicago By-Product Coke Company showing nine sets each equipped with the "mechanical man" of the Western Gas Construction Company.

The advantages of automatic control are evident. In the larger plants, labor is saved; in the smaller plants, the labor used can get results that hand operation cannot rival. Short blows and short runs can be made without loss of time, thereby taking advantage of the economy due to the small percentage of CO_2 made in short hard blows, and more constancy in gas production. More uniform fuel beds can be maintained. Finally, the variable human factor is practically eliminated.

As the general principles of automatic control are well known in the gas industry, the apparatus will not be described in detail. It marked the first step in the march toward complete automatic operation.

Automatic Charging

With automatic control, with heat regulation with high capacities, with quantities of steam, air and oil carefully measured, there was available for the gas industry an efficient and dependable source of gas supply. In this apparatus, however, there were two points of marked inefficiency and two operations which not only required extraordinarily severe labor, but also introduced conditions which decreased capacity, reduced efficiency and, by making it necessary to completely cease operations for a number of hours per day, made a machine which was available for only a portion of the time.

The efforts of engineers for the past ten years have been directed towards solving the problems introduced by intermittent charging and hand clinkering, but only within the past year have these efforts met with marked success.

Messrs. Howard and Stone, in conjunction with The Western Gas Construction Company, have designed and constructed a con-

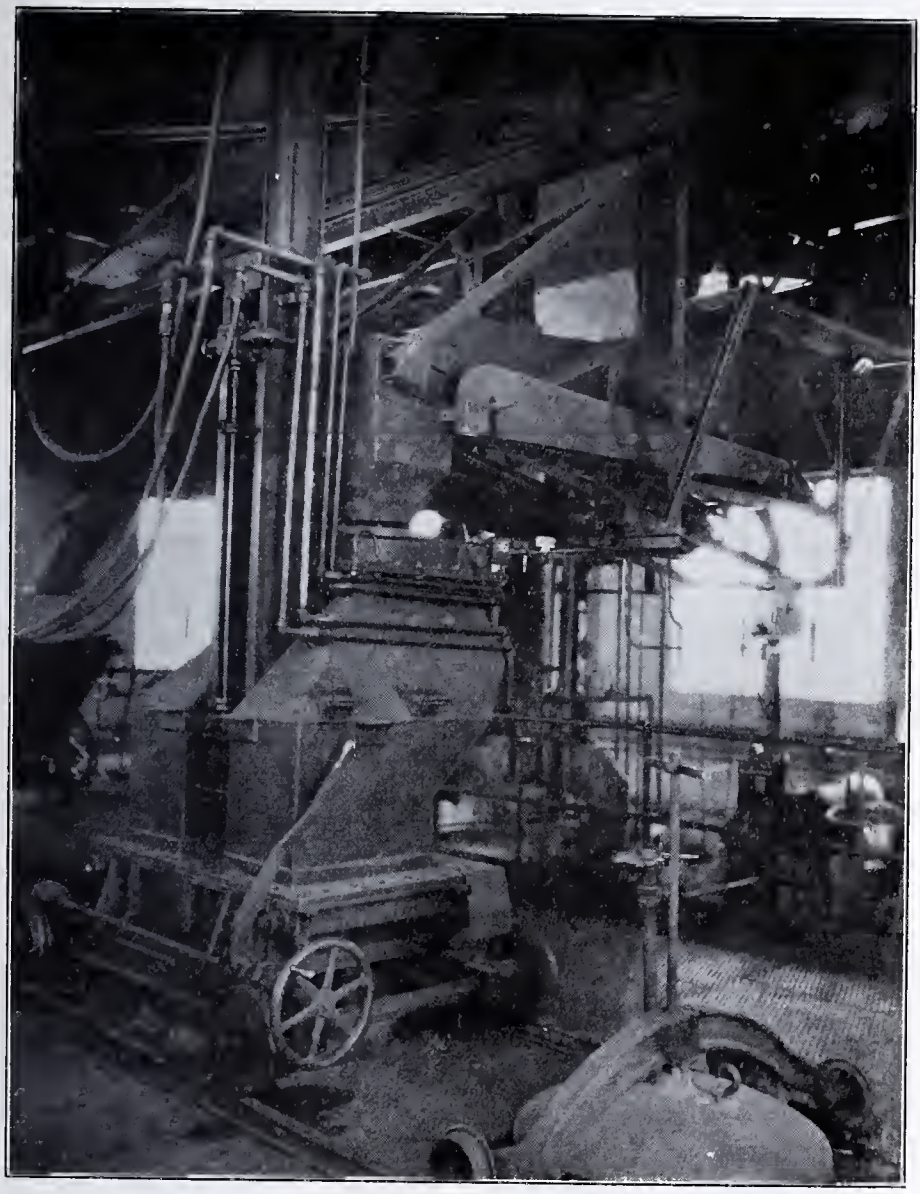


FIG. 5. HOWARD AUTOMATIC CHARGER

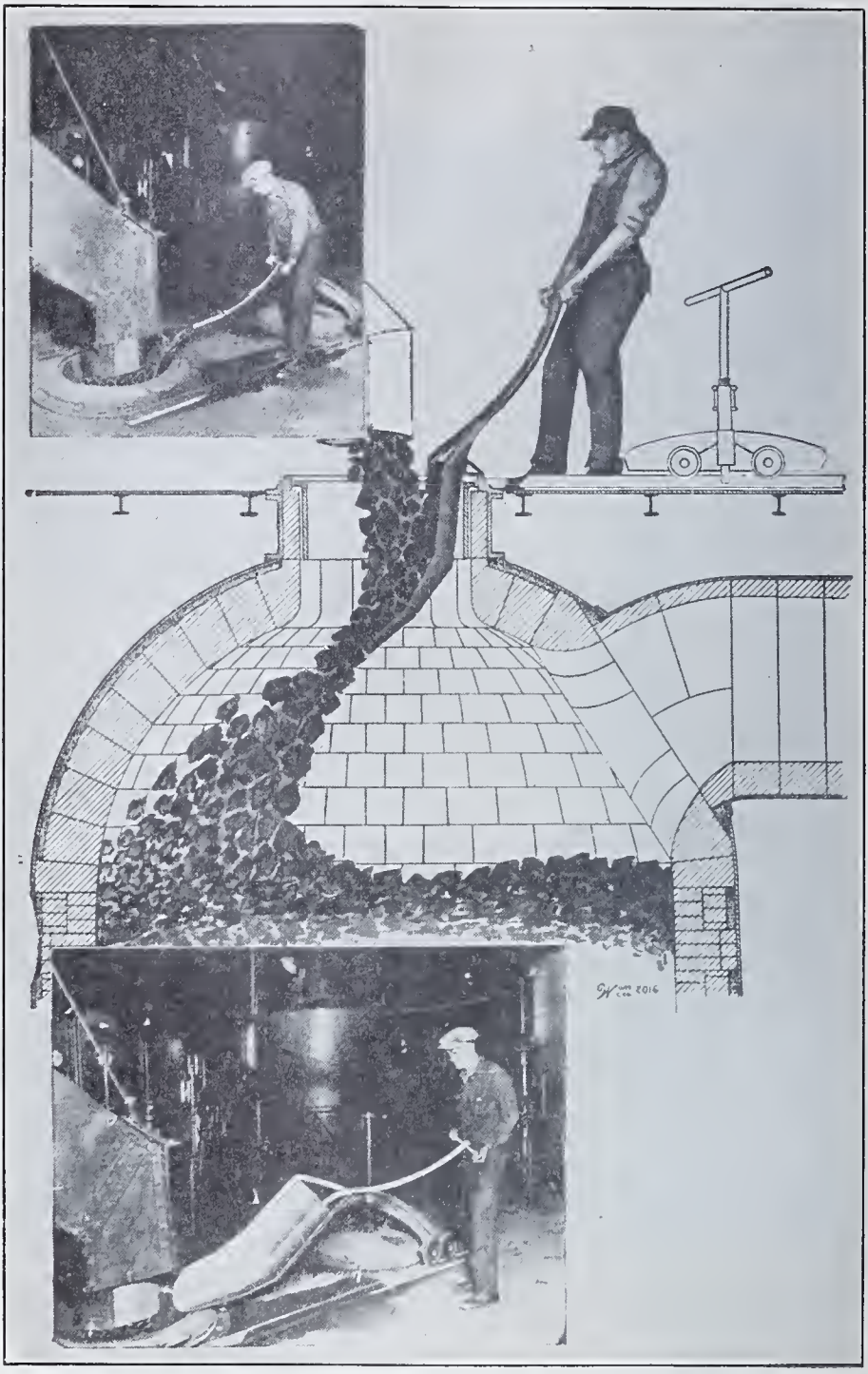


FIG. 6. BEST HAND METHOD OF CHARGING

tinous automatic charging device, the success of which has been demonstrated by nearly a year of successful operation.

The Howard Automatic Charger, complete with automatic weighing and feeding apparatus, as in operation at Fort Wayne, is illustrated in Fig. 5. Fig. 6 shows the best hand method of charging from a larry as practiced at the Chicago By-Product Coke Company.

The Howard Automatic Charger can be fitted over the charging hole of any standard generator and can be quickly replaced by the regular door as desired. The fuel is delivered from an overhead bin into the weighing bucket, which at a predetermined load discharges onto the feed belt. The feed belt in turn delivers the fuel to the charger only during each blast period, at which time the bin valve of the charger is open.

During the down-run the fuel charge is dropped from the charger bin onto a spreader valve which has previously been lowered into the fire. When the charge is released, the spreader is automatically raised from the fire and again seals the charger bin from the fire.

Automatic charging, like automatic control, offers many advantages in the operation of a water gas machine. A uniformly high, active fire is maintained by the addition of small amounts of fuel during each down-run. The four or five minutes per hour shutdown usually required for charging is eliminated. This results in one more cycle per hour, which in the case of an eleven foot genera-

TABLE I

9 FT. WESTERN GAS SET—USING OVEN COKE

	Without Automatic Charging	With Automatic Charging
Total hours running	152.7	142.33
Make per hour—thousand cu. ft.	120.9	125.6
Make per hour per sq. ft. grate area—cu. ft.	3,140	3,260
Fuel per thousand lbs. (coke)	29.7	28.6
B.t.u. per gallon of oil in gas	98,600	102,800
Oil per thousand gals.	2.22	2.38
		2.13 gal for 464 B.t.u. gas
Steam per thousand lbs. (approximate)	35.6	35.9
Per cent down steam	34.5 — 42.9%	34.5%
B.t.u. per cubic foot in carbureted gas	464	486.4
Cycle (blast)	81	85
(run)	181	175

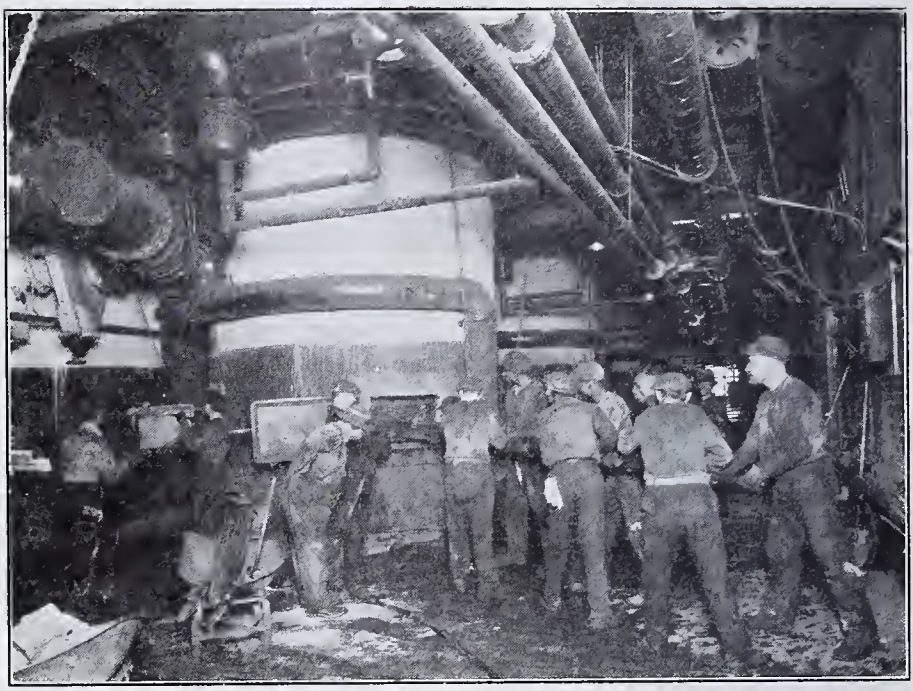


FIG. 7. CLINKERING BY HAND

FIG. 8. CLINKERING BY HAND

tor means 15,000 cu. ft. of gas per hour additional capacity. The top of the fire is kept relatively cool, which tends toward efficiency in blasting without reduction in gas-making capacity. Smoke in charging is entirely eliminated. Better steam decomposition is obtained because of the better fuel bed condition, and clinker on the side walls is reduced because of the fuel distribution.

Table I is a comparison of the results obtained at the Fort Wayne plant in the same 9-foot reverse air blast set, without and with the Howard Automatic Charger. The results are not from a special test, but were obtained in the regular operation of the plant.

The idea of continuous and automatic weighing is not new, but it is our belief that the Howard Charger is the first charger to be developed which has all the necessary functions properly and thoroughly worked out to a conclusion, and one which permits not only the proper and timely inspection of fire control and conditions, but one which may be completely removed and hand charging resorted to in case of necessity.

A-B-C Self Clinkering Generator Base

With the adoption of the Howard Charger but one operation remained to be raised to the level of automatic operation—that is, clinkering.

Removal of the ash clinker by hand constitutes the most laborious and the most disagreeable work in water gas operation. In addition to being expensive from a labor standpoint, intermittent clinkering reduces capacity as the machine is shut down during the clinkering period and both the quantity and quality of gas are low during the period following clinker removal.

This problem has been solved by the development of the A-B-C Self-Clinkering Generator Base, and its efficiency, effectiveness and generally satisfactory operation have been demonstrated by nearly a year of operation at the Chicago By-Product Coke Company, *while increasing the daily gas output per unit.*

From a labor standpoint alone this development is revolutionary. Figs. 7 and 8 illustrate clinkering by hand, an operation which until now has undergone practically no improvement since the first days of water gas. Figs. 9 and 10 are the same type generator being clinkered continuously by the self-clinkering generator base. A comparison of

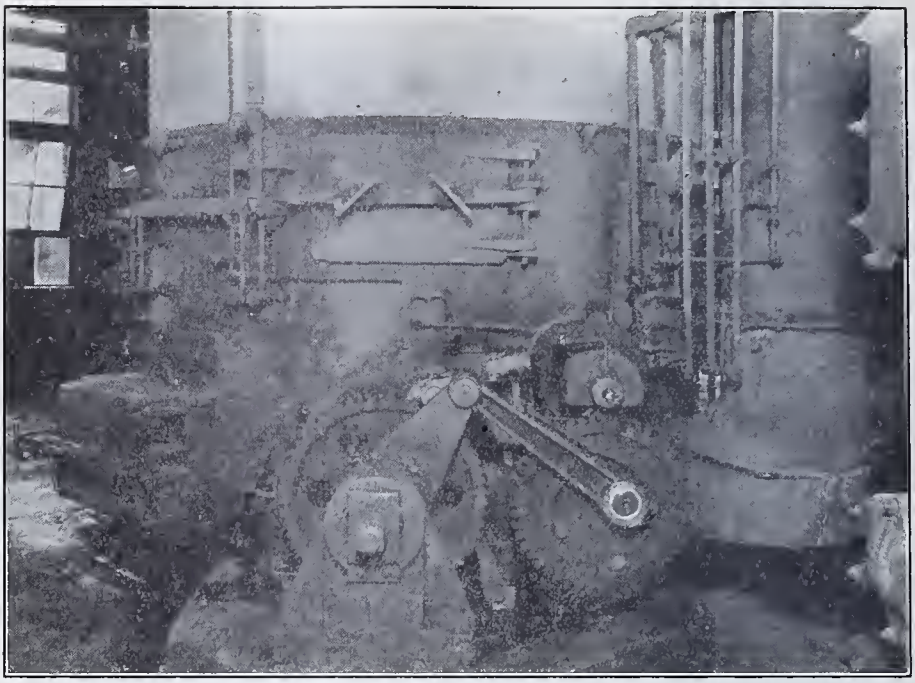


Fig. 9. Self-Clinkering Generator Base

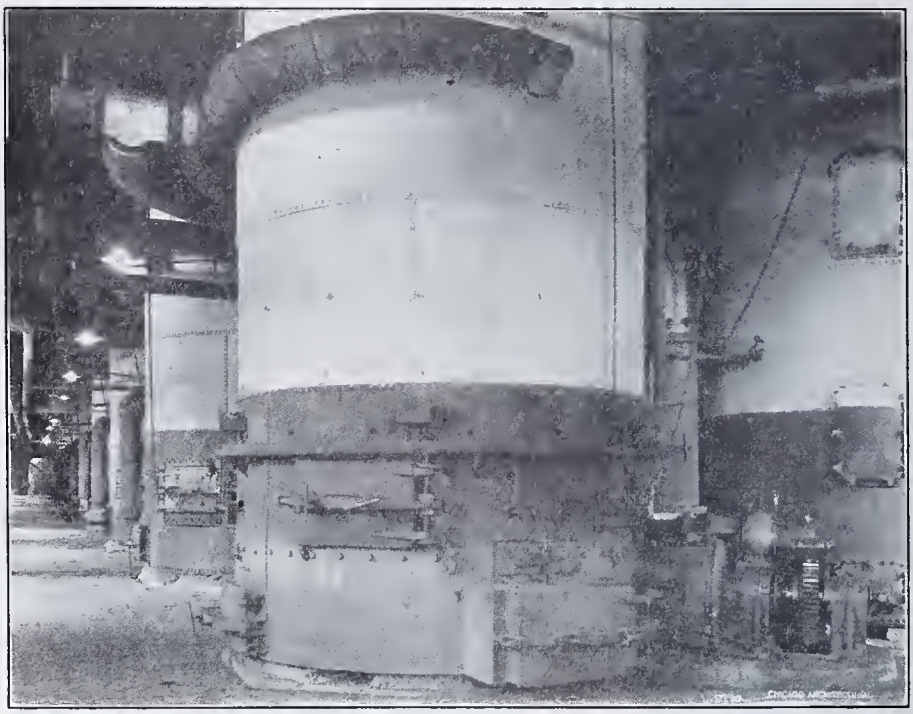


Fig. 10. Self-Clinkering Generator Base

Figs. 7 and 8 with Figs. 9 and 10 speaks most eloquently of the accomplishments of the self-clinkering base. Fig. 11 is a drawing of the A-B-C Self-Clinkering Generator Base.

When one undertakes to perform by machinery, work that was formerly done by hand, he is apt to copy, unthinkingly, the move-

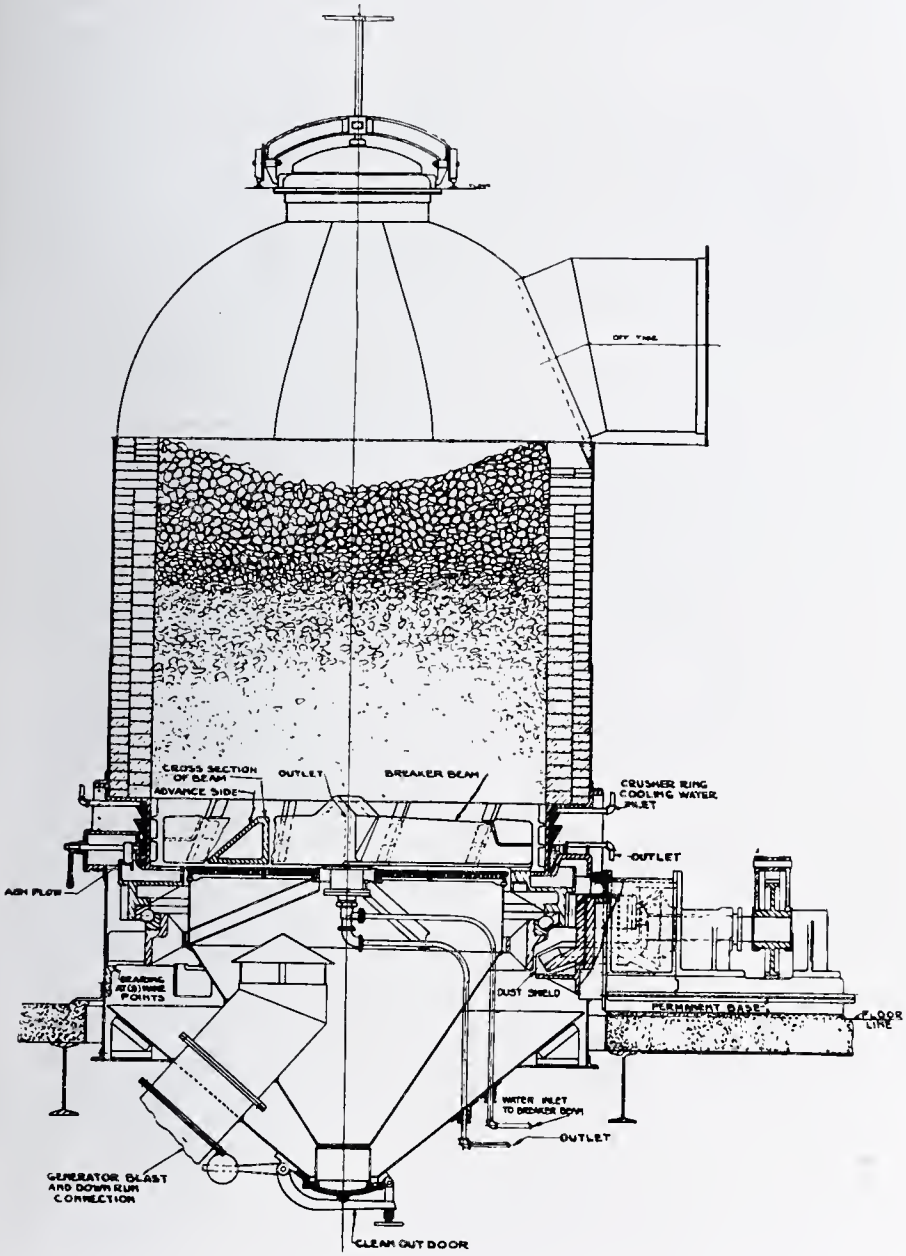


FIG. 11. A-B-C SELF-CLINKERING GENERATOR BASE

ments and the tools of the hand operator, never realizing the much greater possibilities of mechanical power. This has been peculiarly the case in the development of the Mechanical Producer and the Water Gas Generator.

Formerly a poker and a sledge hammer were the only tools available for conditioning a gas producer, and although we now know that poking is not always what the fire bed requires, nevertheless, most attempts to provide mechanical operation, have been along the lines of a mechanical poker. Numerous schemes have also been put forward for breaking up clinkers after they have been formed, but very little has been accomplished to actually prevent their formation. Preventing a disease is better than curing it after it has become malignant, and preventing the formation of clinkers is better than breaking them up after they have started to make trouble.

One should think in terms of what the fire bed needs rather than in terms of what formerly was done by hand. There is no precedent for a thing that has never been done right. To prevent clinkers, and at the same time keep the fire bed sufficiently hot to make good gas, it is necessary to maintain as far as possible, equal density and equal temperature throughout each individual horizontal cross-section of the fire bed, and it, therefore, follows that that motion is best, and that machine is best, which enables one most easily to maintain each horizontal cross-section of the fire bed uniform in density and temperature.

Having clearly in mind the needs of the fire bed and the ideal of "horizontal uniformity," the A-B-C mechanical generator was developed so as to produce a peculiar wave-like motion in the fire bed, starting at the grate, in waves about fifteen inches high and extending upward about five feet, at which level the height of the waves gradually diminishes to nothing. This slow, wave-like motion is exactly what the fire bed needs. It closes the blow holes as fast as they tend to form and thus prevents high-temperature streamlines which are the primary cause of clinkers.

To obtain this motion in the fire bed, there is provided a horizontal grate over which revolves a hollow, water-cooled, cast-steel beam about fifteen inches high, arranged with its forward or working face both up-stroking and out-stroking. The beam revolves at any desired speed from one revolution in twenty minutes to one revolution in one hundred minutes. The up-stroking action pro-

duces undulations through the fire bed that maintain uniform density, while the out-stroking action accomplishes three distinct results: first, it packs the fuel against the wall, thus preventing excessive blast and excessive temperatures along the wall; second, it bores out the center of the fire bed, thus keeping it properly loosened and active; and third, should clinkers be formed, it crushes them against a water-cooled crushing-ring which extends around the wall just above the grate.

To obtain the desired horizontal uniformity in the fire bed it was found that the grate must be horizontal and not conical. It is also necessary that the agitating member be horizontal, instead of vertical. A vertical agitating member leaves a vertical gap in its wake through the fire bed, but a horizontal agitator leaves only a small horizontal gap in its wake, which fills up quickly without disorganizing the fire bed.

The A-B-C generator is the first to make use of the principles stated above. Its success, however, is partly due to a new method of operation which had to be developed before clinkers could be prevented. When it was found that nothing about the machine would break, except the shearing pins, no matter what the load or the temperature imposed, it was discovered that it could be operated at a high temperature with an unusually large amount of down-run steam (70% to 80%) and with practically no ashes upon the grate. This resulted in a more concentrated fire than ordinary practice and a portion of the ash in the fuel was made sufficiently fluid in the hottest zone to permit it to run well down into the zone below it before cooling sufficiently to become solid. In this way the liquid ash reached the immediate neighborhood of the agitating beam before solidifying, and the motion of the beam was found to be sufficient to prevent the cooling liquid from agglomerating in large masses. The beam, therefore, does not have to break up large clinkers so much as it has to prevent their forming. Consequently, the power required is very small, being only about four H.P. on the peak of the working stroke of the ratchet and pawl drive. The equipment, however, is built strong enough throughout so as to withstand 20 H.P. should it be required.

Most of the coke used has been from Kentucky coal mixtures having a high fusing point of ash, 2600° and over. It is believed that cheaper fuels having a lower fusing point may work easier.

The grate is provided with 3/8" vertical slots tapering to 5/8" on the underside. These slots are spaced as close together as possible. When blasting at the rate of 12,000 ft. of air per minute the resistance of the grate is about 2½" and usually the resistance of the 9-ft. deep fire-bed above it is an additional 16". This machine has operated for weeks at a time without a change in the pressure drop throughout the fire bed of more than 3" from the above average. A good deal of attention is paid to the blast pressure gauge, as everything is sure to be going all right as long as the pressure drop through the fire bed remains normal. Should the pressure drop increase materially the temperature of the fire is increased by less up-steam or more down-steam, or more blast as the situation seems to require. However, during normal operation changes in the cycle are seldom required.

Another feature of this generator is the two concentric chambers under the grate. The inner chamber is for the passage of the gases, and is about two feet less in diameter than the inside of the generator. It was found that restricting the gaseous currents to the limits of the inner chamber deters them from concentrating along the walls and assists in maintaining uniformity. The outer chamber is for ash removal and is closed to the flow of gases. Two adjustable plows, one on each side of the generator, discharge into it.

In the flat bottom type of generator the ashes are removed every eight hours, requiring eight minutes each time. In the cone bottom type this time will be greatly reduced. The total time required for ash removal and other causes has averaged about three-quarters of an hour per day. It is expected that in the new cone bottom type the time lost will be about one-quarter of an hour per day.

No hand poking is ever required and practically no clinkers are made. If clinkers do occur they will be located on the refractory lining just above the water jacket and may be melted off before they become objectionable, by making the fire a little hotter.

The fire is withdrawn once a month, at the time the carburetter is recheckered, and the generator is given a thorough inspection. The refractory lining has been in service a year and is still in first class condition.

The main gear ring for the 11-ft. generator is ten feet in dia-

meter, the teeth are 9″ face, 4″ pitch with the upper ends shrouded. They can deliver a force of over 100,000 lbs.

In the year that this machine has been in service, no tooth has broken on any gear, no shaft has broken and no bearing. One agitating beam was worn out at its upper outer corners, but this was largely due to lack of cooling water for occasional periods of a half hour or more during regular operation.

The ash and clinker removed by the standard manual methods contain 35% carbon, while that removed by the self-clinkering base contain less than 20% carbon, representing a saving of 1.6% of the original fuel. Due to the lower carbon content of the ash and the lower temperature of the ash particles, the self-clinkering base effects a saving of 4,550 pounds of coke per day in an 11-ft. set, or 1.24 lbs. per M. cu. ft. of gas.

The cooling water required for the agitating beam and water jacket is 20,000 gallons per day, absorbing 14,000 B.t.u. per minute, which is equivalent to approximately 1% of the heating value of the fuel charged. In plants which have been built abroad with different types of self-clinkering devices, the amount of cooling water is four times this amount.

In addition to the fuel saving, the self-clinkering base results in a better gas yield and a better quality of gas, by keeping a uniformly high and active fuel bed. It also effects a considerable saving in labor costs.

Table II is the distribution of generator labor chargeable to clinkering and charging, under the old intermittent methods.

Table II

	Per year
Cost of clinkering, 11-ft. set, 300 days operation per yr.	$7,200.00
Cost of charging, 11-ft. set, 300 days operation per yr.	675.00
Total	$7,875.00

The saving in the labor item alone would make the fully automatic generator well worth while, but when it is considered that in addition, the quality of the gas made is improved, the capacity is increased and the overall efficiency is enhanced, there can be no doubt but that the generator, complete with automatic control,

automatic charging and automatic clinkering is truly a revolutionary development in gas manufacture.

With reference to operating data on the self-clinkering generator base: The machine built at the plant of the Chicago By-Product Coke Company was in a generator house where there are eight other 11-ft. machines. The demand for gas from this plant is such as to practically preclude the isolation of No. 1 set on which the device was placed, excepting for comparatively short intervals.

Water gas operation and control is so standardized today from a standpoint of interpretation of data that the chance of error in interpretation is remote. This is particularly true of a water gas generator where the variation due to clinkering is eliminated.

Operation with Coke

The machine was put into operation after having had the carburetter brick recheckered, on September 10, 1926. Table III shows the record of a *continuous run for twenty-five* (25) *days.*

Table III

REMARKS	DATE	FUEL USED	NUMBER OF RUNS	ASH REMOVED
Type of Coke Used:	Sept. 10	114,000 "	267	7,280 pounds
	" 11	129,900 "	261	9,135 "
80% Kentucky Coal	" 12	121,100 "	263	10,395 "
20% New River Low	" 13	126,000 "	256	10,640 "
	" 14	131,600 "	248	11,760 "
Average Analysis:	" 15	123,400 "	234	10,570 "
	" 16	119,600 "	215	10,115 "
Moisture 1.5%	" 17	133,900 "	250	10,250 "
Fixed Carbon 90.8%	" 18	132,500 "	249	10,500 "
Volatile Matter 1.2%	" 19	133,000 "	255	12,150 "
Ash 8.0%	" 20	125,200 "	255	11,200 "
	" 21	117,400 "	257	10,500 "
	" 22	123,600 "	252	9,800 "
**Machine shut down 3 hours to change motor.	" 23	**95,900 "	202	9,520 "
	" 24	113,600 "	249	9,485 "
	" 25	118,100 "	274	10,955 "
	" 26	112,600 "	263	9,345 "
	" 27	112,700 "	264	9,870 "
	" 28	117,900 "	264	11,165 "
	" 29	118,800 "	263	10,865 "
	" 30	117,900 "	261	11,165 "
	Oct. 1	106,300 "	252	9,205 "
	" 2	117,900 "	261	11,165 "
	" 3	112,700 "	264	9,870 "
	" 4	96,200 "	247	8,400 "

On October 5 the machine was shut down and the bricks rechecked in carburetter. Upon close examination of the mechanical apparatus it was found to be in excellent and satisfactory condition. The machine was started again and ran sixteen days with the same results as the previous twenty-five days. It was then operated as a gas producer.

On many occasions it has been possible to secure for a few hours the operation of this machine alone. For example, on September 18, the above report shows that the machine was operating normally and used 132,000 lbs. of fuel. During eight hours of the twenty-four hour period all other machines were shut down. This machine produced 1,516,000 cubic feet of 409 B.t.u. gas, using 1.44 gallons of oil per M. cu. ft., so that the gas production for the twenty-four hour period could be deduced to be approximately 4,500,000 cubic feet of gas, showing a fuel result of approximately 29 lbs. per M. cu. ft. Assuming a gas production of 60 cubic feet of oil gas per gallon of oil used, this would show, on the basis of blue gas, 31.7 lbs. per M. cu. ft.

Operation as a Producer

As a gas producer this machine handled up to seventy-five tons of coke per day, a very high capacity. It was decided, however, after six days' operation that the water jacket would have to be made higher in order to prevent clinker formation along the lower fire brick wall, when operated as a producer.

Operation with Bituminous Coal

Tests were made on No. 1 machine operating on Elkhorn egg coal beginning August 2 and running through until August 14. During these tests the amount of fuel used per day amounted to approximately 100,000 pounds. The operation of the machine was, if anything, more successful with coal than with coke, the clinkering conditions indicating that the coal clinker was being handled more easily than coke clinker. The ash in this coal was approximately 3%.

On August 11 it was possible to shut down all of the other machines in the house for a ten-hour test, the result of which show 160,700 cubic feet of gas made per hour, indicating that with automatic ash removal this machine could produce approximately 3,900,000 cubic feet of gas over a 24-hour period. The amount of fuel used per M. cu. ft.

was 28 pounds, while 2.15 gallons of oil per M. cu. ft. were used in the carburetter. The B.t.u. value of the gas was 423. Interpolating these results we find that the blue gas produced by the machine was using approximately 32.1 pounds of coal per 1,000 cubic feet of gas. However, the B.t.u. value of the blue gas was only approximately 250 B.t.u. due to an over-use of the blow run. At the conclusion of this test it was decided by the various engineers and operators conducting the test, that so far as the use of coal is concerned, the following is true:

1. In using a hard lump bituminous coal with low ash, that a make of gas could be secured amounting to approximately 75% of the capacity on coke, and also amounting to practically as much gas as is normally produced with a coke machine without the self-clinkering base.
2. That the fuel per 1,000 cubic feet would amount to practically the same as with coke.
3. That the self-clinkering device operated more easily on coal of this character than on coke.

Plans have been made and construction undertaken for a new unit of this type to be built in Detroit, embodying both the self-clinkering base and a Howard automatic charger. This new machine should go into operation in February, 1927, when more detailed results can be secured.

In bringing this new apparatus to your attention as a revolutionary advance in operation, we do so with a full appreciation of what has been done in England, France and Germany. In these countries there are plants operating with automatic clinkering mechanisms, and also with types of automatic charging. We have, however, been able to learn of no plants where the proper principle has been discovered and applied. Their results have shown that not only has the capacity been cut down to a remarkable degree, but there has been a necessity for a large amount of hand clinkering auxiliary to the machine operation.

Blue gas has many uses, among the more conspicuous being:

1. Carburetted for base and peak load gas.
2. Carburetted for peak load gas.
3. For calorific control of coal gas.
4. As a source of hydrogen in synthetic ammonia and various hydrogenation processes, including coal hydrogenation.

5. As a source of the basic materials for methanol and various synthetic compounds.

6. As a heating gas for coke ovens built before the value of the combination oven principle had been demonstrated.

Economic conditions have brought the gas industry face to face with new problems. The growth in the use of the internal combustion engine, with the resulting increased production in gasoline, will eventually make gas oil so valuable that its use in manufacturing carburetted water gas should and will be reduced to a minimum. Fig. 12 indicates that it is probable that the solution of this problem is to be found in the production of coal gas, diluted with blue gas or producer gas to a fixed quality as a base load. To this base load must be added the peak load gas—blue gas or carburetted water gas.

Although the production of carburetted gas will be gradually decreased by economic pressure, blue gas will continue to grow in importance. It will be the ally of coal gas in serving a broad field of heat utilization, industrial and domestic, and individually will be the source of carbon monoxide and hydrogen for chemical processes of increasing importance.

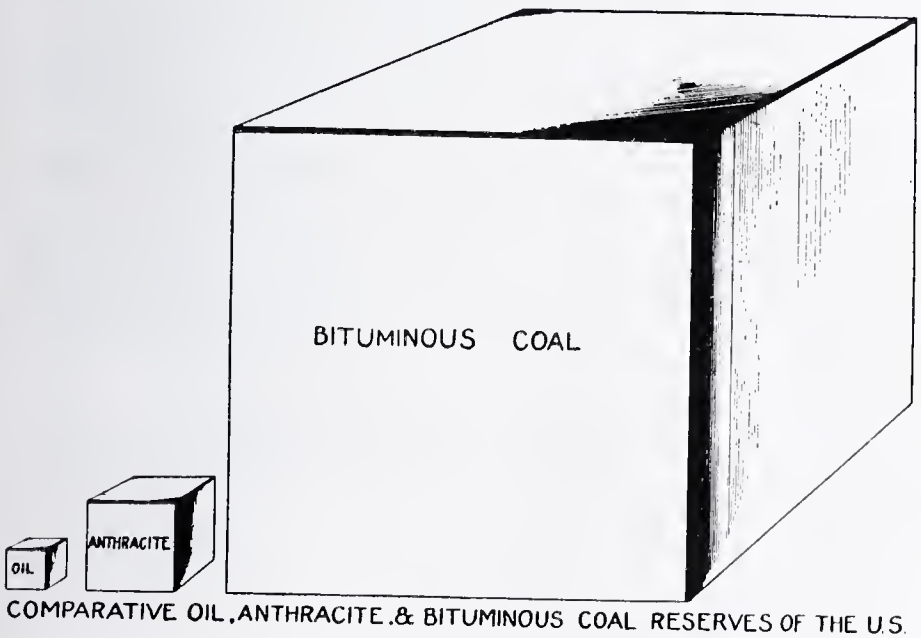


Fig. 12

CONCLUSIONS

A water gas generator or blue gas generator equipped for automatic charging and continuous clinkering has the following advantages:

1. Produces a uniform quantity of gas of high and uniform quality.

2. Secures a practically labor-free operation; such labor as is necessary being confined largely to inspection.

3. Increases capacity over best existing method of operation for the following reasons:

(a) A deep, uniformly-dense fire is constantly maintained, and high blast quantities *assured*.

(b) No shut-down is necessary for clinkering or charging. This increase in operating time results in from 12% to 18% increase in output.

4. Excess steam is reduced on account of a more dense and uniform fire bed. This means not only a saving in steam, but of sensible heat passing out of the set with such excess.

5. Latent heat in blast gases is reduced due to the ability to set and maintain uniform conditions.

6. Increased oil efficiency is secured due to the ability to secure uniform heating, and uniform rate of gas production coupled with uniform excess steam.

7. Reduction in spare capacity needed for a given output, due to elimination of clinker periods.

8. Availability of peak load gas production, since standby generators can be ready to operate quickly and without the necessity of large standby labor force for clinkering and charging.

9. Labor conditions are such as to entirely remove heavy arduous work. Under such conditions better and higher class men are attracted.

10. Makes gas production practically free from menace of strike conditions.

11. Half of the carbon heretofore lost in the ash is now saved in the form of gas.

12. All of the heat heretofore lost in clinkering period is saved.

13. A large saving in maintenance cost of refractory linings, the machine in operation having run a year without replacement.

POSSIBILITIES OF FUEL ECONOMY IN THE IRON AND STEEL INDUSTRY

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The American iron and steel industry consumes approximately 115 million tons or 20% of the country's bituminous coal production. Most of this is completely gasified, either in gas producers or in coke ovens by high temperature distillation and subsequent burning of the coke in blast furnaces or cupolas; a relatively small amount is fired as coal under boilers or for other purposes. Since the consumption of bituminous coal and the production of gas therefrom have reached larger proportions in this industry than in any other, any economies in their use are of far reaching importance. At most American iron and steel plants the opportunity exists for substantial fuel savings, especially by more efficient and more complete use of surplus gases and waste heat.

Improvements in this direction not only offer a field for profitable investment but will result in the elimination of the smoke and dust nuisance which has been generally considered a necessary evil connected with iron and steel plants. A modern coke oven, blast furnace and steel plant using its fuel properly, needs no longer be a menace to pure air, health and the beauty of the surroundings in which it is located.

The author was greatly impressed with the progress in this respect made by the leading iron and steel works in Germany where he had occasion to observe the results of the economical use of fuel at the leading iron and steel works. The smokeless steel plant has become the rule in Germany rather than the exception, wherever coke ovens and blast furnaces are coupled with steel works and rolling mills.

It is generally acknowledged that, during the great development through which the American iron and steel industry has undergone since the discovery of the Mesabi Range, refinements pertaining to fuel economy, unless resulting in greater production as in the case of lower coke consumption per ton of iron at the blast furnaces,

were generally considered last on the program of improvements. Sound reasons governed this policy, principally scarcity of labor combined with unlimited markets. Greater output and labor saving were the chief purposes. American blast furnaces, steel works and rolling mills took the world's lead in production, mechanical devices for labor saving, more efficient scheduling of work and application of labor. The iron and steel industry in this country compared to that of Europe excels in the rational development of balanced output integrated from raw materials to finished products; in simple layout and construction of plant, free from elaborate complications; and also in cost accounting. It also has the advantage of better standardization of production and products.

Capital, as a general rule, was not so readily obtainable for building economical gas, steam and power plants or for the more efficient recovery of the values contained in surplus gases. Complete cleaning of blast furnace gas was not considered economical except for gas engines, and primary washed, and, in some cases even dirty gas is to this day used under stoves and boilers. Coal firing of boilers and heating furnaces in American steel plants is in many instances still carried out without regard to efficient combustion, and the same holds true in England. Waste heat boilers in connection with Open Hearths, it is true, have been developed in America ahead of any country, but their installation was induced in part by a condition resulting from the desire for greater tonnage, necessitating a greater heat input, generally resulting in higher stack temperatures, an effect which may only be modified by the application of the most recent refinements in design and operation.

Higher freight rates and other factors which have developed in this country since the war have made stricter fuel economy almost compulsory. Much progress in the economical use of fuel has been made in more recent years as exemplified by the development of better hot blast stove practice, the installation of efficient boiler plants equipped with means for more perfect combustion in combination with higher steam pressures and superheats, and of larger electric power generating units located in central stations; also the more complete use of coke oven gas, more general application of mechanical producers and other improvements.

Comparing the heat economy as practiced today in Germany with that prevailing in the best American plants, the greatest difference lies in the wide use of the gas engine in the former country, both for blowing and power generation, resulting in a greater percentage of surplus gas becoming available, and the complete utilization of this much greater amount of surplus blast furnace gas in their steel works and mills. They have progressed further in refinements of stove, gas engine and heating practice, as well as in the use of finely cleaned gas for all purposes. American plants on the other hand have gone further in the application of large boiler and turbine units.

There are several steel plants in Germany which, in spite of producing a wide range of products, normally consume no coal in the production of finished steel beyond that charged into the coke ovens, excepting locomotive fuel, and even this is often eliminated by the use of electric or other fireless switch engines; at other plants coal is fired only to generate power for sale or to replace coke oven gas which is sold to communities on account of its higher value. There is no fuel practice in this country comparing with this achievement, even at plants where gas engines are the prime movers.

From the viewpoint of ultimate economy, steel plants should be guided by the principle that blast furnace and coke oven gas should be applied primarily to all uses where a solid fuel cannot be utilized, and then to where a solid fuel can give equally good or even better results, especially under boilers. It is disadvantageous to fire blast furnace or coke oven gas under boilers where cheaper grades of coal applied in the powdered form or on efficient stokers would give excellent efficiency, and at the same time to gasify a more expensive coal for use in heating furnaces, for which purpose blast furnace and coke oven gas could be used to greater advantage. It should always be remembered that the use of blast furnace and coke oven gas for melting and heating saves the cost of gasifying an equivalent amount of high priced coal in the producer.

To gain the proper perspective in dealing with this subject, the iron and steel industry should be regarded not only as a producer of iron and steel but as a potential distributor of gas and power to affiliated

and neighboring industries, public utility companies and communities.

Most of the important steel plants in Germany are tied in with the public utility companies both on gas and power delivery. The exchange of power and the sale of surplus coke oven gas is also practiced in this country. Steel plants, particularly those not connected with blast furnaces, in some cases buy all of their power because the large public power station can sell power cheaper than it can be produced in the average steel works power plant.

This broader conception of the heat economy problem influences the selection of the various gases for specific purposes and widens the field of their commercial application and not only offers possibilities for additional profits, but is a deciding factor in assignng new values to industrial locations. This is borne out by the fact that merchant iron operations have been made profitable, where without the utilization and sale of their blast furnace and coke oven gas in one form or another, they would have suffered in competition with blast furnaces serving steel plants naturally affording such economies.

While the great commercial value of the surplus coke oven gas has been fully realized, blast furnace gas has not been generally appreciated. A few figures, therefore, may be of interest. The coking coal used annually in American coke ovens amounting to say 80 million tons, contains a volume of coal gas released by high temperature distillation aggregating in heat value 448,000 billion B.t.u.'s, which is equivalent to 17.2 million tons of coal. Of this gas, approximately 20% is still being wasted because of beehive ovens. Of the balance a considerable percentage is lost through the inability to utilize the whole of the gas at all times, more particularly the week-end gas.

The total heat value in the blast furnace gas represents even a larger total than that of the coke oven gas. For each ton of pig iron made, an average of approximately 140,000 cubic feet of blast furnace gas is produced. At 94 B.t.u. per cu. ft. this represents an output of 13,160,000 B.t.u.'s per ton of iron. In an annual production of 36 million tons of iron, 473,760 billion B.t.u.'s are produced, which is equivalent to 18,220,000 tons of coal. Since this tonnage is more than the total coal equivalent of the annual coke oven gas production, it suggests strongly the great economic importance of utilizing the highest possible percentage of the blast furnace gas in the most efficient manner.

Aside from a frequently observed failure to adequately value blast furnace gas in the accounting of manufacturing costs, the principal reason for not generally realizing the necessity of economizing with blast furnace gas, is, of course, its low heat value which made it appear unsuitable for metallurgical purposes, and while most blast furnaces, especially those connected with steel plants, sell surplus gas to other departments, much of this is either wasted or used with a low degree of efficiency.

On the other hand the mistake has been made of considering the gas producer function of the blast furnace as of such importance as to make it a reason or an excuse for high coke consumption per ton of iron. Both here and abroad there have been cases where, through the use of gas engines or of very cheap coke, the returns from surplus gas were unusually high and seemed to offset the cost of a higher coke consumption. The blast furnace is essentially designed for reducing and smelting iron ores and is not an efficient gas producer. From the results of experiments made some years ago, the author became convinced that a blast furnace is not a suitable apparatus for making gas as its main product. It is more economical to operate it in accordance with its best efficiency as a reducing and smelting unit, and to produce such excess gas as may be needed for the steel plant from coal direct, by such means and apparatus as are specifically designed to perform this duty. Slagging producers have been designed for this purpose, but the development in cheap gas production will likely be in another direction, since it will be difficult to overcome the loss of the sensible heat in the slag.

The blast furnace should be operated, regardless of the output and quality of its gas, with the lowest possible coke consumption compatible with good quality of iron, by proper preparation of raw materials and the use of the highest practical blast heats. Under such conditions and with modern installations of steam and power plants, as have been built in American steel plants in recent years. 25% of the amount of gas produced by the blast furnaces should be sufficient to operate the hot blast stoves. If gas blowing engines are used, approximately 18% will furnish power for blowing, pumping and miscellaneous blast furnace service; if the usual steam driven turbo blowers are used, approximately 40% is required for these purposes. In the former case 57% of the gas is available as surplus for sale to other departments, in the latter case only 35%. If gas engines are used for

electric power generation, one and a half to two times the amount of power will be developed from the same amount of surplus gas. Nevertheless, the development in this country will very likely continue in the direction of steam turbines. Several German plants have recently installed turbine units and are considering their more expensive adoption for blowing and power generation. The steam turbine has proven that it is capable of high efficiencies if of sufficient size and backed by the proper steam plant. With the expensive skilled labor in this country, the steam turbine has the advantage of low cost of operation as well as installation and will likely be preferred in all plants except where coal costs are relatively high and where gas engines already are the prime movers. There seems to be no probability of any substantial decrease in the cost of gas engines due to quantity production and standardization and the only possibility for a cheaper gas power unit is the gas turbine. In Germany the gas engine has a low initial cost, is operated with low priced labor and has been further developed than here, not only in regard to size of units but particularly in that the waste heat both in exhaust gases and cooling water is fully utilized. Whereas a heat efficiency of 21 to 24% is attained in this country on average plant performance, German gas engine stations are usually operating with efficiencies of from 26 to 30%. They are quite generally equipped with scavenging and surcharging arrangements which enable an increase in the horse-power output without loss in overall thermal efficiency, providing waste heat boilers are installed and the heat in the cooling water is recovered for boiler feed or other uses. Also German plants were early equipped to clean mechanically all of the blast furnace gas so that the cleaning of additional engine gas involved in the aggregate but a small extra expense.

Recent improvements in power plant design and generating methods as embodied in the large American power stations of public utility companies must lead to the conclusion that the iron and steel industry of this country is right in attacking its power problem on the basis that the steam turbine will in the long run prove to be the most suitable prime mover. Modern power stations containing the largest units (50,000 to 77,000 K.W.) are operating with a steam pressure of from 500 to 1250 pounds per square inch and 250° to 300°F. superheat, and can generate a K.W. hour with approximately one pound of coal. Such results correspond to an overall heat efficiency, which is very close to that of the gas engine plant.

A steam plant to attain such efficiencies must be of enormous capacity and represent almost as complicated an installation as the German gas engine plant with its waste heat recovery elements. The turbine plant, however, by encouraging the adoption of large units, as shown by the installation of machines ranging from 15 to 30,000 K.W. at several large steel plants, decreases the first cost of the station and makes it cheaper to operate. The largest gas engine buit in Germany is an 11,000 H.P. unit driving an 8,000 K.W. generator. The fact that the gas engine station needs the steam turbine for flexibility and equalization of its load, suggests the simpler program of installing the steam turbine plant in the first place as a central station containing the largest possible units. In the final analysis it is the cost of fuel and labor which will govern the choice of the prime mover.

Nearly twenty years ago the practice in Germany was to clean all the blast furnace gas mechanically, generally in washers of the disintegrator type. A number of plants have since gone so far as to install the bag filter system, and some the electric precipitation process. At any rate, practically all the blast furnace gas is finely cleaned to .02 grains per cubic foot or below. In this country it was considered economical to wash the gas only to a degree which would permit the use of about 4½" checker openings with 2½" or 3" wall thickness in the hot blast stoves for which a gas cleaned in tower washers was fully satisfactory and gave the desired economy without complicating the plant or adding to the problem of mechanical upkeep. Neither were the boiler plants developed to a state where the necessity for absolutely pure gas existed or full advantage of its use could be realized; in fact it was a question whether there was an economy in washed gas at all for boiler use, due in part to the fact that the gas was not cleaned enough to prevent coating the tubes. It must also be remembered that at that time 1200° F. to 1300° F. was considered a high blast temperature, the low, steep bosh and large hearth design had not reached its full development, and this average temperature could readily be obtained, with a stove capacity comprising not less than two square feet of heating surface per ton of annual pig iron production.

In recent years the use of much higher blast temperatures has generally been found advantageous and is now available at many plants through the use of automatically controlled pressure burners

in connection with modern stoves. With these high heats and the amount of dust which remains in the primary washed gas, considerable disintegration of the brick work occurs, so that the life of the stove checkers, even if of sturdy construction, instead of being 20 to 25 years, as expected, will not be more than 15 years. In Germany with gas cleaned to .02 grains per cubic foot, stove designs have been adopted which use checker brick with only 1″ wall thickness and with openings less than 3″ square or special fillings have still smaller openings. In this manner very much larger heating surfaces have been developed for a given dimension of stove, so that their size or number could be substantially reduced. While such methods result in heat economy, it would seem that the greater possibilities resulting from perfectly clean gas lie in the direction of using a material of greater heat conductivity than fire brick for efficient heat exchange between air and waste gases below a given range of temperature, to replace a portion of the fire brick checkers. Checkers of refractory material must be used and are efficient at the higher temperatures, but a greater portion of the refractory material could advantageously be replaced by metal fillings or recuperative elements.

The great advantage of having perfectly clean blast furnace gas for boilers is apparent today. It should not be applied in any but the finely cleaned state especially where modern methods of heat interchange are used.

This points to the advantage of finely cleaning the entire output of blast furnace gas. In most localities this is still done most economically by the wet process. The recent development in this country of a vertical sectional machine which is flexible, requires little space, and in combination with a stationary tower but little power, is of interest as presenting an alternative to the combination of the tower with the disintegrator type of washer. A gas not containing over .05 grains per cubic foot is suitable for use, not only in stoves and under boilers but for coke ovens, heating and annealing furnaces, and for all purposes where a gaseous fuel of low heat value can be applied.

Owing to its high inert content and low flame temperature, the blast furnace gas is most useful for heating long combustion chambers and flue systems. It gives a mild and uniform heat and a long travel of the flame. Hot blast stoves and coke ovens, the former without and the latter with regeneration, are the best examples for these require-

ments, and afford a very complete interchange of heat, which is particularly desirable when using a high inert gas of low heat value on account of the relatively small differential between flame and waste gas temperatures. Coke oven operators abroad who are using blast furnace gas and those in this country who use producer gas, which is nearest to blast furnace gas in heat value, have found it much easier to maintain uniform temperatures in their flue system than when using coke oven gas. The low flame temperature makes damage to brickwork less liable to occur. A very accurate temperature control is possible because of the nearly equal volume of gas and air required for combustion and because there is but little variation in the composition of blast furnace gas, especially when the same is furnished from more than one furnace.

The high inert content of the blast furnace gas also makes it the most suitable fuel for use in gas engines. This gas on the other hand should not be used under boilers where the cheapest kind of solid fuel can be used to full advantage, such as coke breeze, low grade and slack coal, or waste heat. These sources should form the basis for generation of steam power.

The coke residue from low temperature distillation of bituminous coals may in the future constitute an economical fuel for generating that portion of steam required over and above the amount made from unsalable blast furnace and domestic coke screenings. Wherever public power stations are connected with city gas plants—and large steel works should also be regarded as public sources of gas and power—a low temperature carbonization department would seem to have a place as it is a source of cheap fuel for power and also a producer of both gas and tar. The difficulties in commercializing low temperature carbonization in this country have been the inability to produce a metallurgical coke or even an acceptable domestic coke; briquetting is too expensive to compete with standard American fuels and there has been no market created here for the low temperature tars. However, it may develop that the special value of the gases from low temperature distillation, which is due to their richness and the fact that they can replace oil in carburetion of city gas, may be realized in connection with using the coked residue in power plants, while the tar may be

useful in mixture with gases of low luminosity in metallurgical furnaces until other markets are developed.

There are, of course, a number of isolated blast furnaces in this country, principally such as are not connected with steel works, which have no outlet for their surplus gas in their own plant and for that reason must naturally use their gas under boilers for generating the power required in their own operations. Such plants should seek connections with neighboring industries and public utiity companies, or in the absence of such possible connections, consider whether the cheap source of power which they hold would not warrant the development of industries of their own, principally those which use blast furnace slag.

The opposite condition generally exists in intergrated steel plants where there is not enough blast furnace gas available both for heating coke ovens and metallurgical furnaces, and therefore part of the heating gas has to be generated in gas producers.

The gas producer as generally used in the steel industry furnishes a gas of low heat value, generally between 130 and 140 B.t.u.'s. It is located as closely as possible to the furnace in order to retain the sensible heat which increases its calorific value slightly beyond the figures given. The saving of this heat is not as important a factor in the case of regenerative furnaces where waste heat boilers are used. In heating furnaces using unregenerated producer gas, the sensible heat is essential in increasing the flame temperature. Raw producer gas has the advantage of being the cheapest artificial gas, and the gas burns with a highly luminous flame which is an advantage in metallurgical operations. The disadvantages attached to the use of raw producer gas are that it varies in quality and the control of its combustion is difficult and uncertain, resulting in too much excess air generally being used, which causes heat losses and scaling of the steel in heating furnaces, although this is counteracted to some extent by preheating the air, less oxidation taking place when combustion is hastened. Also gas from many coals contains more sulphur than is desirable for melting steel, which sulphur cannot be removed from hot gas. Because the producers must be located close to the furnace in order to conserve the sensible heat, producer installations become scattered, rendering their supervision and operation more difficult and making it necessary to deliver the coal and steam to many points, conditions which naturally involve a higher cost than would be attained with a large central gas plant. Losses of heat

and excessive labor cost incident to the removal of ashes and clinkers have been largely eliminated by the installation of mechanical producers, but gas flues and checkers become clogged with soot, affecting their efficiency. In order to get the best results, a high grade coal has to be purchased, usually screened coal with a low sulphur content. The use of blast furnace gas for heating steel obviates these disadvantages.

By preheating the air or blast furnace gas or both to various degrees, the flame temperature can be raised in accordance with the demands of the heating process to which it is applied. But it must be borne in mind that actual flame temperatures are always considerably below the theoretical temperatures. Unmixed blast furnace gas is used widely for soaking pits and heating furnaces in Germany, to some extent in England and in one American plant. In many cases it is preferred to producer gas and has the advantage over coke oven gas of giving a milder, longer and heavier flame which can be easier controlled and regulated to its theoretical air requirement, so that less oxidation of the surface of the steel takes place and less scale is produced. The author was impressed with the excellent heating in Germany with preheated or regenerated blast furnace gas. Finely cleaned blast furnace gas is preferred there to producer gas because it keeps the checkers clean and increases the life of the furnace. The excellent preheaters which have recently been put on the market in this country offer the opportunity of preheating both air and gas at a very low cost where the highest temperatures are not required or before admitting them to the checkers. In the development of air heaters with metal sheet heating elements, it is possible with gas temperatures of 1800° F. to preheat the air required for combustion to 1500° F. In the past there has been a great loss of heat in steel plants due to inefficient heat regeneration. In the average heating furnace the temperature of the air has probably not been above 700° F. with waste gases of 1500°.

For melting steel in the open hearth furnace, blast furnace gas has too low a heat value and is too high in nitrogen. For this and other high temperature work it must be enriched. This can be done either by mixing a certain amount of coke oven gas, tar or oil with it or by passing it through a producer.

At many works abroad and at one plant in this country, blast furnace gas and coke oven gas are mixed together, and in the case

of open hearth furnaces some oil or tar is usually added. The general practice is to maintain the B.t.u. content in the mixture within the range where the gas does not have to be regenerated. This mixed gas then is available for all purposes throughout the steel works and rolling mills and also for coke ovens equipped for air regeneration only. On the other hand it would seem that greater economy can be reached by using each gas separately, applying them where they give the best results and where the largest returns can be made. In cases where all of the coke oven gas can be sold to communities or other industries, it would certainly seem that unmixed blast furnace gas should be used wherever feasible.

The other method of enriching blast furnace gas is by passing it through the fire bed of a producer. With the usual types of producer, this cannot be done continuously on account of clinkering. Mr. G. R. McDermott read a paper in May, 1925, before the Association of Iron and Steel Electrical Engineers on the subject of blowing gas producers with blast furnace gas, in which he gave the results attained by alternately blowing air and blast furnace gas up through a hand poked producer. He attained, using coal, a B.t.u. value of 195.2 when blowing with gas, as against 121 when blowing with air, the average gas during the test of 4 hours containing 147.3 B.t.u. As these results are of the greatest interest, the analysis of the resultant gas in each case and of the mixture are herewith given.

	Combined Gas	Gas Blow period	Air Blow period
	%	%	%
CO_2	4.7	3.3	6.0
C_2H_4	0.7	1.0	0.5
H_2	7.2	10.2	6.0
CO	29.6	35.4	23.4
CH_4	2.4	4.2	2.4
B.t.u. low value	147.3	195.2	121.0

Mr. McDermott has made a decided step in the direction of improving producer practice by the use of blast furnace gas in place of steam. The combined gas is relatively high in CO and low in H and water vapor, both of which are undesirable in open hearth and heating practice if present in too high a percentage. Mr. Wal-

demar Dyrssen also has pointed out the advantage of the use of either waste gases or blast furnace gases in producers with the same end in view.

A few years ago the author caused the experiment to be made at the Federal Furnaces at South Chicago, of passing raw and also washed blast furnace gas up through a generator filled with small coke which was heated by downblasting the coke. The average analysis of the resulting gas was as follows:

	Raw Gas %	Enriched Gas %
CO_2	12.0	3.0
H_2	3.0	12.0
CO	27.0	41.0
CH_4	.....	0.2
N_2	58.0	43.8
TOTAL	100.0	100.0
B.t.u.	98.8	169.0

This as well as the enrichment with coal is an intermittent operation, requiring either a mixing holder or preferably two or more machines operating in proper sequence to give a gas of uniform heat value. In case higher B.t.u. values are required, the following method seems feasible. The cycle starts by blasting with air as in water gas practice and burning the blast gases in a suitable regenerator through which both the latent and sensible heat of the gases of the blast period are recovered. The blast furnace gas admitted at the bottom of the regenerator will carry this stored heat back to the fire bed by entering the producer at the top, flowing downward through the fuel bed completing the regenerative cycle by giving up its sensible heat to the fuel and ash bed. The development of the metallic heat interchangers would appear to make this method simple and efficient. Another method which suggests itself is the regeneration of the blast gases in the second regenerator. The theoretical calculation of the heat balance of this process shows a heat value in the finished gas of approximately 170 B.t.u.'s, as corroborated by the experiment. This method seems particularly adapted to utilize the undersized coke which should be screened out of the blast furnace fuel.

It was expected that in passing raw hot gas through an incandescent coke bed, the impurities in the gas would be eliminated through

fusion with the coke ash. The results verified this expectation and indicated that a commercial method of cleaning blast furnace gas and at the same time enriching it might be developed by this method. The self-cleaning water gas generator, which has recently been developed, would seem to offer a suitable apparatus for carrying out this process as it promises to permit of higher temperatures being carried in its fire bed. The economic feasibility of the process will depend on a supply of cheap fuel, being available such as undersized coke and coke screenings.

The advantage of enriched blast furnace gas as compared to ordinary producer gas is its greater calorific value, lower nitrogen content and the lower sulphur in the gas. Its composition gives excellent qualities for heating and melting, and a utilization of blast furnace gas in this manner which would certainly seem to be more economical than burning it under boilers.

The cycle method of operation which is needed to produce gas with a high heat value has not been favored in the iron and steel industry, on account of complications, expense and generally unsatisfactory operation. These objections are largely based on the necessity of having a number of hand operated valves and also on account of the unavoidable shutting down approximately twice a day for clinkering. The output diminishes as clinkers accumulate. This work is of the roughest character, expensive, and the labor increasingly difficult to secure. The formation of clinker prevents the complete gasification of the fuel and thus leads to an appreciable loss of carbon. But these difficulties have been completely overcome by the introduction of automatic, mechanical valve operation and the continuous generator. With the self cleaning grate this generator has been successfully operated with both coke and coal as fuel, showing a very large capacity compared to existing gas producing machines. The demonstrated capacity of a 9 foot inside diameter machine operated as a water gas generator using coke, is 120,000 lbs. per day.

The valuable papers by Fred Clements,† and discussions of the latter paper by Chapman and Siebert gave a great deal of information on the subject of gas making. Mr. Dyrssen has established an equilibrium diagram for the system C, H_2O, H_2, CO and CO_2 at various temperatures of gasification from which he has determined heat and

†(British Iron and Steel Institute 1923) on gas producer practice, and Waldemar Dyrssen (1923 Year Book American Iron & Steel Institute.)

chemical balances for C gasified by the various gases. He calculated the theoretical efficiency of the gasification of C by blast furnace gas as 76.4%, and the heat in blast furnace gas in per cent of total heat used as 17.7%. Mr. Siebert has pointed out that Dyrssen's assumptions were not necessarily correct as far as actual practice is concerned on account of the absence of horizontal zones of approximately equal temperature. This condition should be added to the requirements of a perfect generator or producer and it would seem that the new self cleaning generator would come nearer accomplishing this function than any other gas making machine.

The extensive investigations which have been carried on by the heat economy bureau at Duesseldorf and particularly by Dr. Lent, dealing with the subject of heat transmission from metallurgical gases, have already resulted in a better understanding of the phenomena of heat transmission of such gases at high temperatures. The transfer of heat from gases to solid or liquid matter, has been treated in its four phases, viz, conduction, convection, radiation by gases and radiation by soot and vapors. Dr. Schack succeeded in calculating the radiation and absorption of heat by such gases and he proved thereby—and his theories were upheld by laboratory tests—that it is the CO_2, CO, H_2O and light and heavy hydro-carbon constituents of the flame, which at the higher temperatures increasingly perform the function of heat radiation and absorption, whereas oxygen and nitrogen remain inert, as far as these functions are concerned. Dr. Lent proved the correctness of Schack's theory and calculations by actual tests which were made on a large scale at the Rheinstahl Works.

These investigations show that temperature is the vital factor in influencing the radiation of these gases, while the thickness of the gas body or flame passing over the bath, its concentration and the time element are of secondary influence. The radiation from soot and vapor probably takes place in accordance with the laws of radiation from one solid body to another which is as the fourth power of the difference of their absolute temperatures. The work of Dr. Lent and his collaborators proves the great value of a gas low in nitrogen and of combustion with a low amount of excess air and of a luminous flame. It also explains why a high flame temperature results in a low stack temperature and indicates interesting possibilities for raising the efficiency of the open hearth process by increasing the temperature head. The consideration that only that heat available above a certain degree is effective and that

an infinite amount of heat applied at or below this temperature will produce no results, leads to the conclusion that in order to increase open hearth efficiency a high temperature head is needed, obtainable only by richer gases, which will not dissociate in regeneration.

The open hearth furnace at present is thermally inefficient. Fred Clements gives its thermal efficiency as 16.98% without waste heat boilers. This figure is higher than some given by American open hearth plants. Kinney and McDermott in their paper read before the American Iron & Steel Institute in 1922, gave a thermal efficiency of 14.24% for 1912 and 15.8% for 1922. Dr. G. Bulle gives the efficiency of the process in German plants operating on scrap as 20 to 30%, on pig iron and ore as 10 to 20% and of the Talbot process as 2 to 5%. By recent developments higher efficiencies have been obtained through better methods of open hearth design, causing better flame control. The improvements in fuel efficiency has been coupled with larger production and longer life of the furnace. The application of waste heat boilers has recovered from 10 to 20% of the total heat, 16.4% according to Kinney and McDermott.

The advantages connected with the production in a central station and the use throughout the plant of a clean, low sulphur gas of low inert content, so concentrated or rich in heat value that the cost of distribution is not excessive, are so many that the iron and steel plants should give this serious consideration in their future program. The economical recovery of waste heat from the process, the cleaning and desulphurizing of the gas becomes practical and economical in a central plant, whereas with the present scattered units, such refinements are impossible. The removal of sulpur from coal gases may become economical in itself through the recovery of sulphur as a by-product. As an illustration of the importance of low sulphur gas, a number of plants making alloy or other special steels are now compelled to use high priced, low sulphur oils in their open hearth furnaces. This supply threatens to become more expensive. A paper dealing with the influence of sulphur in the making of steel was read by Mr. A. N. Diehl at the May and October, 1926, meetings of the American Iron and Steel Institute. These excellent papers are of great interest in this connection. All these possibilities are so far reaching and cover such a varied field of application that it is not possible in this paper to enter into a detailed discussion of them. Although every plant has its own problems to solve in respect to fuel economy, none are insur-

mountable. The adoption of one system or the other or one gas or the other depends merely on local factors.

The author has endeavored to show how the fuels available in the steel industry can be used to the best advantage so that a better fuel economy may be attained in its plants, at the same time releasing high grade gas for sale to adjacent communities.

The ideal condition would appear to be the sale of all of the coal gas from high and low temperature distillation, as it is in the field of highly divided distribution and use that this high thermal gas must seek its full value. It seems an economic waste to use it in the larger furnace units of a steel plant if it can be sold to households and small industries. This program also saves all of the week end and holiday coke oven gas and most of the blast furnace gas. Unmixed blast furnace gas should be applied to stoves, gas engines, coke ovens and heating furnaces not requiring high temperatures, and in which this sulphur free gas is of special benefit. Steam should be generated from the fines and low grade coal. For melting and high temperature heating of steel a special gas should be produced in a central gas plant, preferable by the cycle method of operation; in the generation of such gas, sulphur blast furnace gas and undersized coke may be used. This new gas for melting should be low in sulphur, of the highest possible heat value and still capable of regeneration without appreciable dissociation of its constituents. This gas will give higher flame temperatures than have heretofore been reached. The resulting higher head of heat will lead to better efficiency of the process and increased output and will meet the growing demand for quality steel.

The scientific treatment of the fuel question in steel plants has been and is attended with very considerable difficulties owing to the heterogeneous sources of heat and their varied application. However, the great interest in the subject which has been evident in recent years is bound to bring about important changes in this respect. A definite thermal program including the concentration of the gas making units into one central station, should result in a more scientific operation of the heat producing and consuming departments, in substantial economies at the plants and additional revenues for the industry as a whole.

DISCUSSION

WILBERT J. HUFF.* It is with some diffidence that I assume the task of leading the discussion at the meeting of this section, particularly

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because much of the subject matter in the papers before us are matters of practice, dealing with phenomena so complex that no simple theoretical treatment is adequate. A discussion of such matters, therefore, falls to the province of the industrialist rather than the university investigator whose attention must necessarily be limited to the simpler fundamentals.

However, the utilization of bituminous coal as a satisfactory fuel for the modern high capacity of American water gas machine is a development in which all of us may take interest. I am sure that all who have heard the recent reports on the use of bituminous coal made by the Water Gas Committee of the American Gas Association, and the discussions of these reports on the floor of the convention, have been greatly impressed by the importance and very practical character of this development. I venture to predict that the adaptation of water gas practice to bituminous coal as a fuel will be regarded as one of the great achievements in American water gas practice of the present period. The gas industry of this country certainly owes much to the researches which have made this use possible, and should do honor to all who have contributed to the art.

In order to discharge the obligations placed upon me when I was asked to lead this discussion, I shall resort to a few questions, hoping that the responses to some of these questions may give rise to debate, and bring into prominence some matters of importance and interest. In asking these questions I do so with the knowledge that it is often much simpler to ask questions than to answer them.

In explanation of some of these questions permit me to review what would be considered ideal conditions in the generator of a water gas machine.

As all know, the optimum conditions are maintained when the temperature and contact permit a balance between the formation of a maximum amount of carbon dioxide during the air blow, and the minimum amount of carbon dioxide during the steam run. This demands certain intermediate conditions which can best be attained when the blow and the run are short, and therein lies some of the virtues of automatic mechanically controlled cycles. Equally important are the physical conditions within the fuel bed, permitting high rates of air and steam flow and the minimum of temperature variations between various horizontal sections of the fuel bed. Under ideal conditions there are no obstructions or blockage permitting regions of inactivity, and no blow holes permitting excessive temperature variations. To maintain these desirable temperature conditions it is important, of course, that a certain amount of thermal inertia be present in the fuel bed. Thus the refractories in the side wall and in the pier process serve as a storage reservoir for heat, as a fly wheel serves as a reservoir for mechanical energy. A fuel of the proper physical and thermal properties may, however, make the need of the added

storage capacity of the pier wall unnecessary. Thus a dense, blocky coke sufficiently strong to maintain its coherence under the mechanical shocks imparted in the course of water gas generation will have sufficient thermal inertia to avoid localized surface overheating during the blow and localized supercooling during the run. A spongy, friable coke of poor structure and poor thermal conductivity may, however, be expected to give localized overheating and localized supercooling, while the fines may prevent the free access of air and steam to certain regions. In the utilization of bituminous coal as a water gas generator fuel, I therefore deduce that one important desideratum is a fuel bed whose top and side wall temperatures are such that the bituminous coal cokes at a high rate, giving a dense, tough coke relatively large in size, rather than a weak spongy coke obtained by a lower heat differential which necessitates a longer plastic interval during the carbonization.

If these are important factors in the use of bituminous coal, may not the success attained by the hot pier wall be due in part to the rapid coking caused by the high temperature and reserve thermal capacity of the pier?

However, it may be possible to secure this rapid coking by other means. Thus in connection with Mr. Fulweiler's paper I desire to inquire whether or not it is possible to attain rated coke capacities by the use of bituminous coal in an eleven foot water gas set containing no pier, but fitted with the back run connections so that the back run steam superheated by the sensible heat of the checkers may rapidly transfer a part of this heat to the top of the fuel bed and so hasten the carbonization of the bituminous coal to give a blocky strong coke.

I understand that the reverse air blast endeavors to bring about a similar result, and I desire to inquire whether or not this process alone permits the attainment of full capacities when used with bituminous coal in the eleven foot water gas set.

The use of the blow run to maintain a hot generator without overheating the checkers and as a fuel economy measure brings up the question of inerts. If a blow run of sufficient length to effect these desired conditions is used, will not the inerts rise above fifteen per cent? This question or a similar one was asked a few years ago by Mr. Ramsburg, but I for one have never heard a satisfactory answer.

In order to carbonize central district bituminous coal quickly with a low temperature differential, Professor Parr and others have shown that it is only necessary to preheat the coal to a point below the plastic stage. Coals which normally give poor cokes may under these conditions give excellent coke. I appreciate some of the difficulties which would accompany the preheating of coal in water gas sizes—three to six inches—but believe that there are some interesting possibilities here in connection with water gas making and desire to inquire

whether or not any information is available upon the preheating of bituminous coal for water gas generation?

With reference to Mr. Ramsburg's paper, I am sure that I voice the sentiments of all of his auditors when I say that it has been followed with much interest. All of us regret that the time necessarily consumed in the development of the A.B.C. self cleaning generator has so far permitted the testing of only two fuels, one a by-product coke of excellent gas making qualities, while the second was the bituminous coal—Elkhorn—rated by Mr. Fulweiler as the only bituminous coal so far successfully substituted for coke without material change in operating conditions. Unfortunately, many gas makers may not have at their command these excellent fuels. Further reports on the self-clinkering generator using a greater variety of fuels will therefore be awaited with interest.

If we must have a pier process for bituminous coal, how can we use the pier and the self-clinkering generator simultaneously?

Frequent automatic charging of coal in small amounts may be a factor of some importance in quickly carbonizing bituminous coal on the top of the water gas generator. It would be interesting to learn whether or not the Howard charger described by Mr. Ramsburg has indeed been found advantageous in this respect. I note that the Young-Whitwell process for bituminous coal involves frequent automatic charging, and presume that some advantage has resulted due to the rapid transfer of heat through the thin coal layer.

Upon most of the extensive thermal problems of the steel plant presented by Mr. Brassert I hesitate to venture at this time. One point of considerable interest was presented by Mr. Frank F. Marquard, superintendent of the Clairton by-product coke plant, in his discussion before the high temperature distillation section yesterday. This was the record-breaking capacities attained in blast furnace operation when coke made at exceptionally high temperatures was used. These capacities contradicted a theory advanced a few years ago in which it was maintained that a coke containing some volatile matter was best suited for blast furnace operation. An explanation for the results obtained by Mr. Marquard would be very interesting.

This morning in the discussion before the general sessions mention was made of a very promising European development in the art of making water gas from bituminous coal. Further information on this development would no doubt interest the gasification section.

These questions have been asked with the wish that some may stimulate further discussion. I hope that you will pardon me if some are difficult or impossible to answer from the information at your disposal.

MR. FULWEILER. With regard to the first question that Professor Huff has asked about the effect of the rate of heating on the quality of the coke, I can answer by saying that is a factor we cannot de-

termine, but from the results obtained it must be satisfactory.

With regard to the back-run, I think we have enough information to indicate that except in the case of special coals we cannot furnish sufficient heat to carbonize the coal satisfactorily through the use of pre-heated steam alone. Coal seems to require both radiant and conducted heat from the sides of the generator and from the pier. The use of the back-run, however, is undoubtedly of service.

I have no information regarding the results obtained by the use of the down blast. I know that it is being used, and I myself used it 20 years ago.

With respect to the blow run, you can make it of one second or seventeen seconds duration. It is purely a question of economy and that can only be answered by local conditions. In some cases, it pays to make a large amount, in other cases none at all. It is all a question of economics.

The question of pre-heating of the coal is the practice that has been described a number of times. I feel that Professor Parr should answer a question on this subject.

MR. RAMSBURG. I have enjoyed Mr. Fulweiler's fine paper very much and have never been present at a technical meeting where a subject was handled with such force and such clear explanation. I feel, however, that the position of soft coal in water gas manufacture is a limited one, or should be. No large city gas plant should use soft coal, because in so doing we are not taking advantage of proper opportunities. The fuel used should be *coke*.

In making coke, not only can cheaper gas be secured, but in addition we have tar, sulphate and benzol by-products. If the coke can be sold more advantageously than used in comparison with gas coal, then the coal gas capacity is too low and should be built so that the water gas coke should be over and above the quantity possible to normally market.

Why develop new processes to conserve the by-products of boiler fuel and then use coal in a water gas machine? Coal men should remember that in selling a ton of coal for water gas plant use, they defeat the sale of 1½ tons of coal to a coke plant.

W. J. MURDOCH.* The question was brought up whether the use of bituminous coal in the water gas generator could not be accomplished by means of the back run. I say that the back run is a great asset, and with a particular kind of coal there has been successful operation with back run on an eleven foot machine. However, with the pier practice we get about three pounds reduction in generator fuel with increased capacity in the generator effected. I want to bring out the point that the back run is essential, but you can effect much greater economies by the addition of the pier process.

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MR. W. B. CHAPMAN.* Professor Huff raised the question as to whether or not the pier process is applicable in connection with the agitating beam that is being used in Chicago. The first beam we used was straight or level across the top and had no upward projection in the center. We found, in experimenting with this first beam, that there was a slight tendency for the fire bed to become dead in the middle, as is the case with all water gas generators. We then made an extension in the middle of the beam, projecting so that it acted like an augur and bored the fuel out slightly from the center of the generators, stoking it towards the wall, so that we obtained as active a fire in the center as elsewhere. In fact, for the first three feet up from the grate the fire has usually been slightly hotter in the center than elsewhere. We don't believe in the theory that if the fire is too hot along the wall you should also make it too hot in the center by providing additional walls in the form of a pier in the middle of the generator. The air blast and the steam runs, in going up along a wall, only have half a chance to make gas for there is fire on one side only. The brick lining on the other side cannot make gas. The success of the pier process is not questioned for stationary, hand-operated generators, but if you have a beam, and stroke the fire against the wall, you overcome the looseness along the wall which is the cause of the excessive blast along the wall, and you overcome it in the proper way, because you leave the rest of the fuel bed uniform, as it should be. Therefore, in answer to the question as to whether or not the pier process is applicable to a mechanical generator of this sort, I would say it is quite unnecessary.

W. J. MURDOCH. In answer to Mr. Chapman's statement that the pier process is not necessary with the mechanical generator we feel that without the pier process on bituminous coal operation you cannot effect all economies possible and that this process is highly essential. If the mechanical generator becomes standard equipment, since necessity is the mother of invention, we see no reason why the mechanical generator cannot be designed so that the pier can be used in conjunction therewith. The pier is a simple non-mechanical device to accomplish that which has been claimed for it by Mr. Fulweiler and which thus far we believe has been accomplished in no other way.

MR. W. H. GARTLEY.† They say that the bar strokes the clinker of the fuel bed outward and packs it around the generator wall. Have you used a straight or curved bar, and which do you think does the best work? I mean a straight bar as compared with a curved one of a spiral nature, which takes the ash from the center and moves it uniformly towards the periphery?

MR. CHAPMAN. We have tried both straight and spiral beams and while the spiral is, of course, more out-stroking, nevertheless, the

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†Chief Engineer, Philadelphia Gas Works, Philadelphia, Pa.

straight beam seems to loosen the fuel sufficiently in the center and packs it against the walls with sufficient force to crush the clinker as fast as it forms. To do the same amount of out-stroking the straight beam merely has to revolve a little faster. The shape of the beam is largely a question as to whether one wishes to emphasize its out-stroking effect or its up-stroking effect. Experimenters in the past have neglected the up-stroking effect, which accounts, in part, for their failure. It is very necessary to have the motion imparted by the beam extend as far as possible up into the fire-bed, in order to reach the zone where the trouble is starting. The chief effort should be to prevent the formation of large masses of clinker, rather than to crush them after they are formed.

L. J. WILLIEN.* In regard to the question raised by Dr. Huff about the effect of the backrun process when using bituminous coal in the manufacture of blue gas, I do not know whether it is possible or not to carbonize bituminous coal by passing steam through it superheated to the extent it is by the backrun process. I do believe though that the backrun process does tend to increase the percentage of coal gas in the resultant blue gas.

Less than a year ago I received a copy of the results of an extensive series of tests made with two different kinds of bituminous coal. The tests were made with an 11 ft. set equipped with the backrun, but not the pier. The results included average analyses of both the blue gas made during the uprun and the backrun. From these analyses I calculated the percentage of coal gas in the blue gas by Mr. Wills' method which Mr. Fulweiler mentioned in his paper. The results of these calculations are given in Tables I and II.

These calculations show that the blue gas made during the backrun contains almost three times the amount of coal gas made on the uprun, indicating that the superheated steam must result in an appreciable distillation of the bituminous coal. It is also interesting to note that the B.t.u. of the coal gas made during the backrun is lower than that made during the uprun. This is to be expected because of the cracking of the hydrocarbons in passing through the hot fuel bed.

Similar calculations made from an average analysis of the blue gas made in a 9 ft. water gas set that was not equipped with a backrun, showed 8.3% of coal gas in the blue gas. The B.t.u. of the coal gas was 538.

The question was also raised concerning the rate of carbonization of bituminous coal when used in a water gas machine. It is the practice in many plants using bituminous coal to use a long blowrun immediately after charging, believing that by so doing a great deal of coal gas is given off and blown over the relief holder. Table III shows

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analyses of the gas taken from the top of the wash box of a 6 ft. set when using bituminous coal. The gas at this point was a mixture of the blue gas and oil gas.

These analyses indicate that the evolution of coal gas does not start until the second and third run after charging. This statement is based on the percentages of illuminants, CO and CH_4.

TABLE I

CONSOLIDATION ELKHORN COAL

Over 2½"—Bar Screen

Size of coal used	1½"+	2½"+	Unscreened
B.t.u. of uprun blue gas	335	337	327
B.t.u. of backrun blue gas	363	351	376
Per cent coal gas in uprun blue gas	11.9	11.2	9.3
Coal Gas B.t.u. in uprun blue gas	780	776	883
Per cent coal gas in backrun blue gas	27.9	27.0	29.6
Coal Gas B.t.u. in backrun blue gas	620	590	645

TABLE II

BOONE CHILTON COAL

Size of coal used	2½"+	2½"+	Unscreened	1¼"+
B.t.u. of uprun blue gas	329	349	351	348
B.t.u. of backrun blue gas	382	385	397	391
Per cent coal gas in uprun blue gas	9.7	11.4	11.8	12.1
Coal Gas B.t.u. in uprun blue gas	765	810	840	800
Per cent coal gas in backrun blue gas	31.5	26.7	27.8	29.0
Coal Gas B.t.u. in backrun blue gas	625	650	680	660

TABLE III

Run after coaling	1st	2nd	3rd	4th	6th
CO_2	4.0	4.2	4.6	6.0	4.0
Ills.	7.8	9.1	13.5	7.6	8.4
O_2	0.7				
CO	27.9	15.9	16.2	21.9	24.5
CH_4	19.4	25.8	23.7	20.1	20.2
H_2	35.8	40.0	30.5	39.6	36.9
N_2	4.4	3.9	10.6	4.2	5.3

A. Bement.* One of the foremost problems in the use of coal is that of handling the ash remaining as a residue after the coal is burned. Handling the ash is a distinct, separate and special problem from the other phases of conbustion or gasification. Usually attention centers on the combustion process with ash disposal considered as a secondary matter, while in many cases it is really a matter of primary importance. The Koppers Company have rendered a service of tremendous value to the gas and coal industries by development of the automatic self-cleaning producer, which, together with automatic and uniform feeding, presents two of the most important developments that have been available to the gas industry.

One of our fundamental difficulties in arriving at a proper value of coal is the special prominence given to the analysis and B.t.u. as a measure of quality, which in no way indicates the effect on performance due to the size characteristic; in other words, size of the pieces of the coal. It is altogether probable, as Mr. Fulweiler intimates, that the use of coal of unsuitable size and uniformity, has been an important cause of much of the difficulty experienced in the use of coal as a water gas generator fuel. Coal of irregular size or containing duff or screenings will make a fuel bed that is too compact in part, while at the same time it will be unduly open and free in other portions. Good results require that the coal be as near uniform size as practicable and that the dimension of the pieces suited to the size of the generator fire.

I am not familiar with any extended research in this respect, as applying to gas making. Experiments in steam production, however, may be quoted as illustrating the value of size characteristic, as distinct from chemical composition of B.t.u. content. The following table presents results from experience in steam production with different preparation of the same coal burned on natural draft chain grates:

Relative Value of the Small Prepared Sizes of coal as compared with screenings, as Stoker Fuel in Steam Production. Determined by Test.

Trade Name Used to Designate Preparation	Size	Relative B.t.u. Value	Relative Value as Expressed by Mine Price	Relative Service Value on Basis of Test
Screenings	1¼"x0"	1.000	$1.00	1.00
No. 4 or Pea....	¾x⅜	1.009	1.36	1.38
No. 3 or Chestnut	1¼x¾	1.024	1.43	1.47
No. 2 Nut.....	2x1¼	1.038	1.51	1.86

The fourth column, that of service value, is a composite of efficiency of combustion and capacity for steam production.

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COAL IN RELATION TO THE PRODUCTION OF FIXED NITROGEN

By Louis C. Jones
Nitrogen Engineering Corporation, New York

Chronologically, Chile nitrate was first used as artificial nitrogen fertilizer and then came by-product ammonia in the form of sulphate, keeping step, of course, with the production of coke and gas in by-product ovens in city gas works and in Mond Producers. Along with the use of potash, Chile nitrate and by-product sulphate, developed acid phosphate. The Norway Arc Process began operation in 1905, and about the same time production of cyanamide started in Europe, both depending entirely upon electric power, and using large quantities of it.

In 1912 then, we have besides potash and phosphate, four sources of nitrate: Chile, and three artificial forms—by-product sulphate, Norway nitrate, and cyanamide—the latter rapidly increasing in importance. In this situation evidently electric power was absolutely essential in the fixation of nitrogen, ammonium sulphate being a by-product of the iron industry, where coal is, of course, the mother material. Coke is absolutely essential in making cyanamide, but fuel is of little importance in the production of potash, Chile nitrate, and acid phosphate; and Thomas slag is, of course, another by-product of the iron industry.

The 300,000 tons of nitrogen as sulphate of ammonia produced annually represents the use of (say) 150,000,000 tons of coal, principally in the iron and steel industries.

Coal and coke are, however, used in large amounts primarily for nitrogen fixation in the Haber type of process, which today represent 80% of all the world's production of artificially fixed nitrogen.

Contrary to general impression, coal and coke—not hydroelectric power—are the most important factors in fixing nitrogen today. The predominating importance of hydroelectric power in this industry immediately terminated upon the advent of the Haber plant installed, on an industrial scale, at Oppau, in 1912; but the

impression still prevails everywhere—in non-technical circles—that power is all-important in nitrogen fixation. This false impression has continued perhaps longer than it otherwise would due to the fact that enormously high pressures—not power—are used in these synthetic processes; and also in this country in the popular mind are inseparably linked artificial nitrates and power at Muscle Shoals.

Since the beginning of the Haber Process (and under this name I include all systems involving the direct synthesis of hydrogen and nitrogen under pressure, by means of a catalyst) two enormously important plants have been installed in Germany, in both of which hydrogen is produced direct from coal and coke. The two Haber plants next in importance in the world are the Syracuse plant built in 1921, now producing 12,500 tons of nitrogen; and the Billingham, an English plant built in 1923, now producing 12,500 tons of nitrogen annually, and greatly increasing. Both use coal and coke. The original Haber plants in Germany, one built at Oppau in 1912, and the other at Merseburg in 1918, now have a combined capacity of 450,000 tons annually.

Plants using the Claude System in the U. S. l'Azote near Charleston, West Virginia, (operating on gas from coal have a capacity when operating of (say) 7,000 tons of nitrogen) and similar plants in Europe have about the same capacity (7,000 tons of nitrogen). In addition, Casale plants using coke oven gas produce another 6,000 tons of nitrogen. This, with some production in Japan, gives the grand total of nitrogen now fixed annually through synthetic processes from coal and coke of (say) 500,000 tons.

Fixation of nitrogen, with power as the prime factor, is carried on in Norway to the extent of 35,000 tons. Scattered Claude, Casale and Fauser plants, using power for electrolytic hydrogen in Italy, Japan and the United States, produce perhaps 20,000 tons of nitrogen.

Nitrogen is now being fixed in the form of cyanamide at the rate of about 90,000 tons annually, and not increasing. In other words, in addition to the 300,000 tons of nitrogen made from by-product coke ovens we have a total world's production of nitrogen of about 645,000 tons, of which 500,000 (or nearly 80%) is produced from fuel and without the essential aid of hydroelectric power.

From power the production portion of the world's total is about as follows:

Power { 12% Cyanamide
5% Arc
3% Electrolytic

Not only is 80% of this fixed nitrogen made from fuel processes, but of the increased production of about 100,000 tons yearly probably more than 80% is being installed to use fuel processes. Although the hydroelectric processes for producing fixed nitrogen, i. e., the Arc and Cyanamide Processes, were developed at least ten years ahead of direct synthesis, still the latter process has so far outstripped all competitors that it now produces four-fifths of the total product.

Furthermore, since the great war practically all increase in production of fixed nitrogen has been brought about through the direct synthesis processes; and most of this synthetic product comes from fuel and not power.

A further potential production of enormous quantities of fixed nitrogen lies in the gas from by-product coke ovens. For example: the 150,000,000 tons of coal now producing 300,000 tons of by-product nitrogen as sulphate produce at the same time 10,000 cu. ft. coke oven gas per ton, half of which is hydrogen of very low value as now used for heating purposes. This 5,000 cu. ft. of hydrogen per ton of coal coked would combine with one-third the amount of nitrogen to produce 125 lbs. fixed nitrogen per ton of coal coked. Assuming half this hydrogen could thus be utilized, we would have a potential production of fixed nitrogen of over 4,000,000 tons annually. I have used the word "potential" in connection with by-product coke oven gas for fixing nitrogen because I consider the actual utilization of this gas for synthetic ammonia manufacture has not yet been solved industrially.

The use of hydrogen obtained from coke oven gas by liquefaction processes has developed slowly, due to the difficulty and expense of obtaining, in this way, satisfactory gas for the synthesis operation. None of this type of operation has so far given entirely satisfactory commercial results.

In the synthetic process it is of interest to compare the advantages of fuel with electric energy for electrolysis. Our careful esti-

mates of the cost of producing sulphate of ammonia where both power and fuel are available under otherwise identical conditions—covering all costs, including labor of operation and capital charges—indicate the cost of the product is the same when $3.00 coke and $1.80 coal are compared with $10 H. P.; $6.30 coke and $4.00 coal with $15 H. P.; or $9.66 coke and $5.80 coal with $20 H. P. In other words, there are few, if any, localities in the United States where prime electric power can be purchased for $20, and many places where coke can be had for $6.30, corresponding to $15 power. In general, in industrial centers the demand for power is bound to make its cost prohibitive for nitrogen fixation in competition with fuel.

This situation in the United States is similar to that in Europe where several synthetic ammonia plants were operating during the dry period last summer at reduced capacity because part of the electric power was required for public service.

In remote localities on deep water away from industries' competition, there will be developed nitrogen fixation plants to utilize the cheap hydroelectric power there available.

By your permission, I will take a few minutes to discuss the relation of artificial fertilizer, especially fixed nitrogen, to the world's food problem.

The fertilizer problem concerns the average human being, not his moral or mental welfare, but as an animal. How many are there of these animals; how rapidly are they increasing; how much food do they consume; where do they get it; in what form and how transported; how many of these human animals will this earth support under ideal conditions, supplemented by all artificial methods of increasing the food supply; and besides, what is the effect of surplus food and luxuries upon the world's population?

It will be apparent how confusing are the data available. Nevertheless, there is sufficient evidence to show that the world is not now hungry for food, but for luxuries, and that fertilizer is not needed to produce more food, but to produce it with less labor and more cheaply.

People have lived on this earth a long time, and the world's population has always approached a condition of equilibrium with the existing factors limiting its increase. The earth has, at all times, been

saturated with people. Food supply, i.e., the ability to get it, at first as one animal against another; then successively with weapons of stone and metal used in the hunt, and as tools in agriculture, has been the controlling factor. As population became more dense, disease and war also increased in importance as limiting factors, supplemented by primitive facilities for transportation on foot, with beasts of burden and by water either to bring food or take people to new lands.

The discovery of new continents started a new era in opening up enormous new areas, then supporting sparse and less progressive populations, and the general equilibrium between population and food supply was for the first time completely upset. The invention of machines supplanting human and animal labor for manufacture and transportation—and along with it only a little later the development of modern sanitation limiting disease and pestilence—have, on the whole, given the world a food supply that has never since failed. There has, indeed, been want of food locally; but since the arrival of the machine and sanitation eras the world's population has never been able to catch up with the supply of food. Modern industry, commerce and sanitation, now enable hundreds to live in luxury where one savage barely existed before, and our food supply is greater than ever.

These modern developments have released more than half the people from drudgery in the production of the necessities of life to engage in supplying the insatiable human desire for luxuries, all the way from a comfortable bed to an ocean yacht. Our railroads in the United States are hauling, every year, a ton of freight 5,000 miles for every man, woman, and child.

To what extent lengthened span of life, family well being, late marriage, birth control, industrial employment of women, love of luxuries and similar social factors brought in with our modern era counteract the stimulus of abundant food supply and sanitation as affecting the world's population, is impossible to tell; and there are fewer, but bigger, wars.

Still—in spite of conflicting forces—the world's population is increasing. We are told it is now about 1,800,000,000 and they eat at the rate of 2,000 calories per day, (say) 6.6 bushels of wheat and rye, and

100 lbs. of meat yearly, or, more grain and rice and less meat. But all our statistics are confusing.

In the United States we are increasing at the rate of 1,600,000, say 1.6%, yearly. Still, farms in New England and old England are being abandoned, arable land in New York alone is reverting to brush, according to Baker, at the rate of 200,000 acres yearly. Harvested crop acreage in the United States has fallen by 19 million acres in the last five years. Horses and mules in the United States have apparently been replaced by tractors sufficient to release 9.5 million acres. Millions of tons of food produced are consumed in industry, and cotton is being replaced by Rayon. There are 500,000 reindeer in Alaska where 4,000,000 can be supported, and in the Sub-Arctic regions of British America perhaps a billion can be supported. Instead of being driven to vegetarianism we may need to eat more meat and less wheat. Each European appears to require, say, 6.6 bushels wheat and—according to Hall—2½ acres cultivated land, but the yield per acre has more than doubled in Germany.

Europe lost 13,000,000 in population during the decade of the great war, but is now gaining by 4,000,000 per year. Statistics for China and India are very inaccurate, showing great fluctuation in the population. Still, Dr. Lung, in the last (November 26th) issue of the Scientific Monthly shows that China can readily support double its present population of (say) 440,000,000. The world's grain supply is increasing over the past 25 years at the rate of about .7%, and on this basis (as good as any) the present increase in population of the world annually would be over 12,000,000—let us say at least 10,000,000. It seems safe to say that the world can easily supply food for double or even quadruple its present population, and that means a long time before saturation is reached.

It is not, therefore, lack of food that now limits population. It is the new forces, social and psychological, that came into play when the old restraints were removed.

When the crisis of saturation comes (if it does) from increased population (and it is increasing) we can use much land now untilled; we can save much food now wasted; we can use millions of square miles additional of grazing lands; we can irrigate more; we *may* stop using arable land for production of wine and liquors; we can replace all horses, mules and dogs with tractors; we may, with new strains of

grain, grow two crops per year instead of one; we can fill the Sub-Arctic with reindeer; and we can, of course, practically double the yield per acre by application of fertilizers.

Fertilizers are used today, however, not because we need more food, or more cotton, but because it is the economic thing to do, to save labor, to produce crops cheaper.

According to Bueb, a balanced plant food added to our average soil, consisting of 1 part nitrogen, 1 part K_2O and ¾ part P_2O_5, will yield 20 parts additional grain, or, each ton of nitrogen applied gives 660 bushels of grain.

We are now putting on our soil about 1,000,000 tons of nitrogen and presumably getting in return for it 660 million bushels of grain. But our world's production of all grain is probably 25 billion bushels including rice, only (say) 2% depending on fertilizer; while if we should go to the extreme and double the yield per acre, this 12 billion bushels would require (say) 18,000,000 tons of nitrogen; and it is not outside the realm of imagination that the world could consume something like this amount of nitrogen merely to save cost and labor.

On this basis, then, we have a right to be optimistic regarding the unprecedented possibilities for the use of artificial fertilizer supplied to the farmer at prices constantly stimulating its further use.

With artificial fertilizers available in practically unlimited quantities, we see no possibility of a world food shortage for an indefinite period, and when it comes it will be no worse than it has been in the past when population has been limited by inability to get food, or to transport it. The average man is not going to starve (though thousands now die every year of hunger, more—I believe—die of over-eating) and when we want, we shall make food from coal or wood. Our Sunday newspaper may supply the family's Sunday dinner.

The consumption of the prospectively enormous amount of fertilizer will require a great amount of fuel, or equivalent of electric energy, (say) five tons of good coal and coke per ton of nitrogen fixed; but the total amount will still be small compared with

that used in the iron and steel industry. In other words, our fuel supply will not halt fertilizer production.

I have attempted to show how

(1) Artificial fertilizers, especially nitrates, originally absolutely dependent on hydroelectric power, are now produced in largest quantities and most economically by fuel processes—and essentially without power. In remote localities, hydroelectric power can be used to advantage.

(2) The economic balance between fuel and hydroelectric power under normal conditions in the United States for the production of 2,000 lbs. nitrogen through the synthetic ammonia process has been indicated; i. e., 5.8 tons (2,000 lbs.) coal and coke, at $6.25 per ton coal, against 2⅓ H.P. at $15 per year.

(3) In by-product coke oven gas there is a potential world's capacity to produce say 4,000,000 tons fixed nitrogen.

(4) The world's population is not now, and will not be, limited for a long time by lack of food supply. Double or quadruple the present population can be supported.

(5) The production of artificial fertilizers is increasing, far more rapidly than population, and the amount that can be consumed depends purely on the economic factor of greater net financial return to the farmer by their use.

(6) Coal, in its relation to fertilizer, is importan in three ways:

(a) In the production of by-product sulphate.

(b) In supplying hydrogen through water gas for direct synthesis, and

(c) In the potential production of fixed nitrogen from hydrogen from by-product coke oven gas.

COAL AS A SOURCE OF FERTILIZER

By HARRY A. CURTIS

Professor of Chemical Engineering, Yale University

We may say that bituminous coal is related to fertilizer production in at least three different ways: First, as a source of the necessary power for manufacturing fertilizers; second, as a raw material from which some of the intermediate products in fertilizer manufacturing may be derived, as, for example, the hydrogen used in ammonia synthesis; and third, as a material actually containing one of the fertilizer elements, namely, nitrogen. The present paper will be limited to the last named consideration, that is, bituminous coal as a source of nitrogen for fertilizer use.

Let us first turn attention to a few of the important technical and economical facts regarding the production and sale of nitrogenous fertilizer from coal under present practices. These facts may be briefly summarized as follows:

(a) Less than one-fifth of the final nitrogen in coal is ordinarily recovered in by-product coking. Taking the average nitrogen content of such coal as is coked at 1.45% complete recovery would yield about 145 lbs. of ammonium sulphate per ton. The average for all coke ovens in the United States is a little over 22 lb. or 15%. The low yield of ammonium sulphate is, of course, not due to a low recovery of ammonia from the gas but to the fact that less than one-fourth of the fixed nitrogen in coal yields ammonia when the coal is carbonized.

(b) Since the value of the fixed nitrogen recovered from coal is but a small fraction of the total value of the products of carbonization, the quantity of fixed nitrogen recovered from coal will bear no relation to the demand for nitrogen compounds, but will be limited strictly by the quantity of coal carbonized for the sake of the major products.

(c) The actual cost of producing ammonium sulphate in a by-product coke plant is much below that at which the synthetic product can be made by any process now available. This fact, coupled with the requirement that for most purposes coal gas must be scrubbed free

of ammonia, makes it appear that ammonium sulphate or some other nitrogen containing compound will be recovered in coke and coal gas plants almost regardless of the price level at which fixed nitrogen will move. Likewise, the by-product ammonium sulphate must be absorbed by the market before competing synthetic products can move, for the latter will be produced only in such quantity as will supply that part of the demand not satisfied by by-product ammonium sulphate.

(d) The sale price of by-product ammonium sulphate has never been determined directly by its cost of production. Per unit of nitrogen it has sold at approximately the world market price level for equivalent units of nitrogen. This level was, until recently, set by Chilean nitrate; but again, curiously enough, the sale price of Chilean nitrate has not been determined directly by the cost of production, the usual operation of economic laws being upset by the Chilean monopoly on nitrate. With the event of synthetic nitrogen products in the market, Chilean nitrate is now for the first time facing competition. Presumably air-nitrogen products can be produced at a cost per unit of nitrogen lower than the old price levels, and if this be so, we must expect a lower return in the future from sale of by-product ammonium sulphate.

(e) Despite the prospect of a somewhat lower sale price, production of by-product ammonium sulphate will increase in the United States during the next decade and probably also in several other countries. The estimated increase in the United States production for the current year is set at 12%. These are some of the facts in the situation as it now stands.

It is particularly appropriate to inquire at this time, when so many new schemes of coal utilization are under discussion, how the factors effecting the production of nitrogenous fertilizer from coal are likely to be changed.

Turning first to the low-temperature carbonization, light is thrown on the question of studies which have been made of the distribution of the nitrogen amongst the various products—gas, liquor, tar and coke —when coal is carbonized. We choose for illustration the results pub-

lished by Simmerbach in 1914, obtained with a Silesian coal carrying 1.4% total nitrogen.

DISTRIBUTION OF NITROGEN WHEN COAL IS CARBONIZED

Temp. of Carbonization		Percentage of Nitrogen appearing in			
degrees C.	Coke	Gaseous Nitrogen	NH_3	Tar	HCN
600	71.69	18.13	7.81	2.12	0.25
700	65.43	12.13	18.13	3.65	0.66
800	63.65	10.73	21.28	3.47	0.87
900	58.40	12.14	24.12	4.15	1.19
1000	49.98	21.53	23.15	4.11	1.23
1100	41.39	30.51	23.09	3.70	1.31
1200	26.43	45.10	22.84	4.21	1.42

If Simmerbach's results are correct, it is evident that a low-temperature process operated below 600 degrees Cent. will give but little ammonia. Above 600 degrees Cent. the yield of ammonia increases rapidly up to a maximum at a temperature range somewhat below that used in the by-product oven, and then remains almost constant at a little below 25% of the total. So far as low-temperature carbonization is concerned, we must apparently be content with a low yield of by-product ammonia.

It will be noted that the nitrogen remaining in the coke steadily decreases as the temperature of carbonization rises. Beyond 900 degrees Cent. all the nitrogen released from the coke appears as free nitrogen in the gas. There is presumably the possibility that a coke process may be found which will release the nitrogen from coke as ammonia rather than free nitrogen. We know, indeed, that simply steaming the hot coke will accomplish this end to some degree, and that by such means a higher yield of ammonia is actually in certain processes, but it doesn't pay to steam coke solely for the recovery of additional ammonia. The only point we wish to make here is that the upper limit of ammonia recovery in coking processes is not *necessarily* limited to the 25% indicated in the table given above.

In the hydrogenation of coal, Dr. Bergius has found that approximately 50% of the nitrogen in coal is converted to ammonia. This will presumably double the yield of nitrogenous fertilizer which can be secured from coal. With the prospect that coal will presently be-

come one of the world's chief sources of oil, through the application of such processes as that of Bergius, this high ammonia yield is a matter of considerable importance for the future.

Various new processes of carbonizing coal have been described at this Conference, such as the McEwen-Runge, the Green-Laucks, the Carbocoal, the Carbocite, that of the Fuel Research Board, the Piron, the Bussay, the L. & N., the Parr, etc. So far as we are aware none of these yields as much ammonia as the ordinary coking processes now in general use. Since, however, these processes are not likely to reduce the amount of coal coked in ordinary ovens or retorts, but will increase the total amount of coal carbonized, the use of such processes will increase the quantity of nitrogen recovered from coal. But for a long time to come the amount of fixed nitrogen produced by new processes will be relatively small.

While the ammonia produced in coal processing will probably always be recovered and sold as a by-product, the importance of coal as a source of nitrogenous fertilizer will probably grow relatively less. Coal contains at best less than 3% of nitrogen, whereas air contains about 75% by weight, and it appears logical that any large demand for nitrogen must be supplied from the air. Not many years ago Chilean nitrate constituted the main supply of nitrogen for fertilizer. Then for a few years by-product nitrogen from coal held first place. But to-day the air supplies more than all other sources combined, by-product nitrogen holding second place. It is unlikely that the relative positions of the three main sources of nitrogenous fertilizer will again be changed.

ECONOMIC ASPECTS OF THE FERTILIZER INDUSTRY

By Charles J. Brand
Executive Secretary and Treasurer,
The National Fertilizer Association

An international conference on bituminous coal is an occasion extraordinary, and it is very fitting that the great institution of agriculture should have its place on the program. Not only are the farms of the world, and particularly those of the United States, large consumers of both bituminous and anthracite coal as such, but they are enormous users of the products of the industries that rely upon bituminous fuel as one of their chief raw materials.

Farm implements and farm machinery are one of the important outlets of the iron and steel manufacturers of the world, in which bituminous fuel plays an indispensable part. Last year the value of farm machinery sold was almost $400,000,000.

Many scores of by-products of the coking of coal are included among the goods consumed on farms. An intimate and direct by-product of coal, more largely used in agriculture than in any other single industry of course, is sulphate of ammonia. I will not attempt any discussion of the technical phases of sulphate of ammonia production, but will confine myself rather to those general considerations that affect agriculture and the fertilizer industry as a whole, in order that those responsible for the production of by-product and synthetic materials may the more clearly understand the problems involved and hence the more successfully deal with them.

Greater Total Farm Production Not Required

We are confronted with a situation, particularly in the United States, in which existing demand does not call for a greater aggregate production of farm products. We need only consider the situation as to cotton and corn to get the picture clearly in mind. With a consumptive requirement of approximately 13,000,000 bales of American cotton for the world as a whole, we have a production of practically 18,000,000 bales. We cannot in conscience hope to sell more sulphate of ammonia, more nitrate of

soda, and greater quantities of air-derived nitrogen merely to increase production of cotton when the quantity already in hand must be sold at an average of no less than five cents per pound below the cost of production.

It is necessary that we devise a formula grounded on sound economics that will call for a production as near to world needs as can be secured by human adjustments with reference to an occupation whose results depend more upon nature than upon man.

The demonstrations of the experiment stations and the experience of hundreds of thousands of practical farmers suggest a labor-saving program dependent upon the more adequate use of plant food. This is a problem in which the coal industry has a collateral interest and one that is receiving assistance from the interests responsible for the distribution of sulphate of ammonia within our country. A suggestive view of results that may be attained is afforded by many crops but by none more pointedly than cotton and potatoes which will serve as illustrations.

The South Carolina Experiment Station has demonstrated that by the adequate use of chemical plant food alone a saving of over $42 per bale in the production of cotton can be achieved. Land otherwise practically identical, unfertilized, produced 495 pounds of cotton in the seed per acre; while fertilized with 800 pounds of complete fertilizer it produced 1164 pounds. This means that with complete plant food 7.8 acres produced 6 bales of cotton; whereas when no plant food was used it required 18.2 acres to produce 6 bales.

The fundamentally sound economics of purchasing chemical plant food is adequately demonstrated by this illustration. However, another striking one is so readily available that we direct attention to it.

Potatoes respond to fertilizer in an especially notable way. The six greatest potato-producing states, in the order of their average yields per acre, are as follows:

	Average acreage	Average production bushels	Average yield per acre bushels	Estimated Fertilizer used, 1925 tons
Maine	129,200	31,725,000	245.5	185,000
New york	330,200	40,820,600	123.6	390,000
Michigan	329,600	35,063,000	106.4	101,000
Pennsylvania	248,800	26,449,000	106.3	326,000
Wisconsin	293,000	30,585,600	104.4	12,599
Minnesota	394,000	38,524,200	97.8	5,000

Minnesota, with less than 98 bushels produced per acre, uses practically no fertilizer. Wisconsin uses a little more and has a yield of 104 bushels. Pennsylvania uses still more shows a yield of 106 bushels.

In New York the practice of fertilizing potatoes is gradually becoming more general. Her yield approximates 127 bushels per acre. The State of Maine, one county of which—Aroostook—uses fertilizer in relatively adequate amounts, has a yield of nearly 246 bushels per acre. The counties aside from Aroostook use very little fertilizer and consequently have low yields, thus pulling down the Aroostook County yield. The intensive production of Aroostook County gives yields almost identical on the average with those obtained in Germany.

Attention is called to the fact that the estimated amount of fertilizer used in 1925 in the above tabulation includes that applied to all crops. In Maine, practically the whole amount is applied to potatoes. In states like New York, Michigan, and Pennsylvania, a larger part of the fertilizer is used on other crops, particularly on grains, tobacco and truck.

In a recent demonstration in California, a ten-acre field, adequately fertilized, produced an average of 1000 bushels of potatoes per acre.

Commercial Plant Food Used Insufficient to Maintain Soil Fertility

Declining yields, due to soil depletion, have served notice on farm operators throughout the world that even the richest soils are not inexhaustible. The agricultural plant is depreciating and no sinking fund is being provided to cover the depletion. Despite this situation, the profits from agriculture are insufficient to warrant the producer spending money in many cases on a suitable soil improvement program. Farmers also, due to failure to correctly assess the position, no sooner suffer a financial reverse than they cut down on their purchases of plant food. As a result, whereas our annual crop removals require 9,000,000 tons of nitrogen per year in their elaboration, only 5,450,000 tons are replaced; 3,500,000 tons of this quantity being supplied by the manure and wastes of the farms themselves. This leaves an annual nitrogen deficiency of 40%. It is estimated that combining the consumption of ammonia, phosphoric acid and potash, the leading crops remove from the soil 17,000,000,000 pounds annually, valued at about $1,250,000,000. This is roughly one-ninth of the total value of the crops produced.

The National Industrial Conference Board in its noteworthy report on the agricultural situation has estimated that there is restored to the land only about 2,400,000,000 pounds of plant food in the form of commercial fertilizer, valued at about $225,000,000. In addition the farms themselves restore possibly 8,700,000,000 pounds more of plant food in

the form of animal manures and other wastes. There is left a deficiency due to overdraft of about 5,800,000,000 pounds, valued at approximately $400,000,000. In other words, we are drawing from the bank of agriculture each year in the United States $400,000,000 more than we are depositing therein.

It is the duty of the fertilizer industry to collaborate with the forces of agriculture and other interested parties to bring about the adoption of a soil fertility program that will do away with this uneconomic depreciation of an indispensable manufacturing plant—the soil of American farms.

In view of the great interest in and importance of the cotton situation a few added comments may be in order. Wide-spread agitation for "diversification" of crops indulged in by every one from the president to the rural mail carrier conveys the misimpression that diversification is not practiced in the cotton belt. As a matter of fact the Southeastern states already devote over 60% of their tilled lands to other crops than cotton. About 18% is planted to miscellaneous crops including wheat, oats, peanuts, tobacco, potatoes and hay. Nearly 43% is given over to corn, and less than 40% to cotton. In Texas on the contrary nearly 64% of the cultivated acreage is devoted to cotton. Why the South clings to cotton appears from the fact that although less than 40% of her acres are planted to it, she derives almost 61% of her income from it. With nearly 43% of acreage planted to corn this crop provides less than 19% of the farm income. Is it not possible that cotton is after all the economic crop to produce?

We have only to note what happened to fertilizer consumption in 1921 after a small, low-priced cotton crop to see the close interdependence between cotton prosperity and the fertilizer industry. In 1920 the cotton states used 5,200,000 tons while in 1921 the tonnage fell to 2,921,000—a decrease of 47.8%.

How the agricultural debacle affected the farm implement, vehicle and machinery business is shown by a drop in originated tonnage handled by the carriers from 3,324,000 tons in 1920 to 1,666,000 tons in 1921, a loss of 50%.

ARE FERTILIZER PRICES ON A FAIR BASIS?

This is a constantly recurring question. Most farmers—especially those who do not have the facts—believe fertilizer prices are too high relative to other commodities, particularly as compared with farm prod-

ucts. What are the facts? For admittedly unfair price exactions create intense unfriendliness toward an industry. The problem of a fair price has been a subject of economic discussion since the day of the monastic writers. Competition has been too keen and often ruthless to enable any one in the chemical plant food business to charge all the traffic would bear.

The Bureau of Labor statistics price series of 404 commodities includes in the chemical group the most important fertilizer materials—such as sulphate of ammonia, nitrate of soda, acid phosphate and the various potash salts. The report showing price relations for October has just been issued.

All commodities index number is	150
Clothing stands at	171
Fuels at	184
Iron and steel at	135
Lumber at	181
Farm Products at	139
Other Building Materials at	163
Fertilizer materials at	104

The farm wage level at the date of the last quarterly report stood at 174, while the general level of factory wages stood at 221.

Fertilizer materials were the lowest priced sub-group in the whole list.

Sulphate of ammonia prices contribute to the low price level. The average price in 1913—the basing year—was $3.31 per 100 pounds; the average in 1925 was $2.57—now it is lower.

The sound economics of substituting low cost fertilizers for high cost labor in farm production is clear, but it takes a long time to drive such facts home to the farmer. This is particularly true when he is in an adverse financial position.

How Much of Each Important Plant Food Does the American Farmer Use?

I have recently conducted a survey of the analysis of the fertilizers made and used in America in 1925. 3,222,000 tons, or 43% of the total consumption, were reported upon. Expressed in terms of ammonia, 152,000 tons were supplied in American farms in 1925. This in terms of fixed nitrogen amounts to 125,000 tons. The available phosphoric acid

content was 812,000 tons, while potash as K_2O amounts to 205,000 tons. The total for the three important components was 1,169,000 tons.

The average of each compound expressed in percentages was:

Ammonia	2.04
Phosphoric acid	10.89
Potash	2.75

This makes the average analysis 15.68%, which represents a good advance in plant food content compared with previous periods.

Higher Analysis Fertilizers

Among the developments of recent years none was more important than the trend away from fertilizers containing 10 or 12 units of plant food per ton to those containing 14, 18, 24, 30 and even higher numbers of units. A unit is 1% or 20 pounds per ton, so that you can readily see what this means in the way of growing concentrations. The economy of using these higher analyses is readily apparent when it is stated that the cost of freights alone may be reduced from one-third to one-half by this means. Naturally, the expense for bagging, handling costs and other similar expense was likewise reduced with the growing economy in plant food use. On the other hand, we are still inexperienced in the practical application of concentrated chemical fertilizers with the result that on occasion unsatisfactory experiences occurred through burning and injury either to the seed, the young plant or even the more mature growth. The fertilizer industry has aided in the development of this desirable trend toward higher analyses.

Hydro-electric Power and Fertilizer Manufacture

When air derived nitrogen first began to assume a place of imporance, it was believed that cheap hydro-electric power was an indispensable factor in its production. With development of the synthetic ammonia process, this situation no longer prevails. Despite this fact, literally hundreds of thousands of people still believe that a great water power such as the one the nation owns at Muscle Shoals, Alabama, is important to the cheap future production of chemical plant food. The whole trend of the fertilizer industry due in part, in fact largely, to the prevailing and inevitable freight rate structures in our country, calls for production units of medium size fitted to supply the fertilizer needs of areas within reach at reasonable freighting costs. The development at Muscle Shoals for fertilizer production would necessarily have to combat this situation

and it would be relatively impossible to produce fertilizer cheaply under the circumstances even if the enterprise received a direct or indirect government subsidy. The fertilizer industry has always taken the position that the enterprise at Muscle Shoals should be devoted as fully as possible to national needs and that when these have been supplied, all surplus power should be sold on a competitive basis to any industry that requires power. There is quite as much reason to subsidize some fraction of the shoe or textile industries as there is to set up a subsidized fraction of the fertilizer industry to compete with the remainder that must operate on private capital in open competition with all comers. An endless amount of misinformation is distributed on this subject.

My own view is that the use for the nation's future to which Muscle Shoals power can be put is to develop the industries of that area as industry has been developed in North and South Carolina. North Carolina, for instance, in 1900 produced $94,000,000 of manufactured goods; in 1923, $951,000,000. In the same period illiteracy dropped from 28.7% to 7.6%, and the expenditures for education rose from $1,600,000 to nearly $30,000,000.

Chemical Plant Food and the Future

Our population has grown from 5,000,000 in 1800 to over 105,000,000 now and we continue to increase at the rate of about one million and a half persons per year. The population of the world as a whole has grown from less than six hundred million when Columbus discovered America to one billion eight hundred million now. Chemical plant foods can be relied upon to help sustain a population twice as great as could otherwise be sustained when once their value is understood and they are intelligently applied.

THE RELATION OF COAL TO FERTILIZER

By F. G. Cottrell

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The present relation of coal to fertilizer is predominantly through ammonia, either recovered from coke oven gases or prepared synthetically, and both of these subjects have been so adequately treated for the purposes of this meeting by the preceding speakers, that it would be difficult for me to add anything were I to confine myself to present practices or even projects which have already established their claims to serious economic consideration. I trust you will therefore bear with me if I leave the solid ground of present accomplishment and pass in review necessarily very sketchily over a few possibilities for the future which seems at least to justify careful study by those of us whose particular responsibility after all is more for the future than the present.

Of the approximately $225,000,000 spent annually in this country for fertilizers, we may say roughly that nitrogen and phosphorous each represent about $100,000,000, potash making up the remaining $25,000,000.

Not only is potash a relatively miner part of our fertilizer bill but under present practice its relations to coal are chiefly of a routine nature, through mining, transportation, evaporation of solution, etc., calling for little discussion here. A number of high temperature processes for the extraction of potash from silicate rocks and other minerals have been proposed and in some cases commercially operated, but in nearly every case the commercial production of the potash has to be postulated on the recovery of other valuable products as well, so that were we to try to follow the relation of coal to potash recovery in his group, we would soon find ourselves hopelessly lost in the economics of the related industries such as portland cement, alumina, iron and steel and the like.

The case of phosphorus is somewhat different. Our great natural supplies of this element are the beds of "phosphate rock" or tri-calcium phosphate, notably in Florida and Tennessee, in the East and even

more extensive though less developed deposits stretching through Utah, Idaho and Montana in the West.

Up to the present, practically all of this material eventually reaches the farmer in the form of "acid phosphate," containing about 16% P_2O_5 and made by treating the finely ground rock with an equal weight of commercial sulphuric acid, thus forming a mixture of mono-calcium phosphate and calcium sulphate, which sets in a dry chalky mass, which after recrushing and ripening in storage by allowing the last traces of free acid to combine with the excess rock is ready for application to the ground by itself or in mechanical mixture with potash and nitrogen compounds as "mixed fertilizer," so typical of American agricultural practice.

It will be noticed that in this whole process, including the sulphuric acid manufacture, coal scarcely enters at all.

Emphasis has already been laid by the preceding speakers on the growing interest in more concentrated fertilizers and the savings in transportation and handling to be thus effected. So far as phosphorus is concerned, this means ultimately the complete separation of the phosphoric acid from the calcium, sulphuric acid or other diluent This may be done in two widely different ways. (1) By starting out much as at present, but using 50% more sulphuric acid and separating the very soluble phosphoric acid from the nearly insoluble calcium sulphate and gangue by leaching, decantation, filtration, etc. (2) By volatilization of the phosphorus directly from the rock in a furnace.

It is naturally the various modifications of this second method which hold the greatest interest for the coal industry. The most significant industrial developments thus far have employed the electric furnace. About 1915 the Piedmont Electrochemical Company at Mt. Holly, N. C., experimented with a 5,000 kw. furnace, but encountered difficulty in collecting the phosphoric acid out of the furnace gases. Shortly thereafter, similar but smaller scale experiments by the Bureau of Soils(1), resulted in overcoming these difficulties and furnishing an industrially available procedure. It was not, however, until after the war that in searching for new uses to which to put an electric furnace plant built at Anniston, Ala., during the war for ferro-manganese manufacture, that the new industry as such was really established(2).

The electric furnaces of essentially the same design as those used

[1] Jour. Ind. Eng. Chem. 9, 26-31 (1917) and 10, 35-38 (1918).
[2] Jour. Ind. Eng. Chem. 14, 630-631 (1922).

for making calcium carbide or ferro alloys are fed with a mixture of phosphate rock and coke, together with enough silica to flux the lime of the rock. The process can advantageously employ much of the lower grades of phosphate rock rejected by the sulphuric acid process because of their content of iron alumina and silica as these substances render the furnace charge self-fluxing. Elementary phosphorus is liberated as gas in the more strongly reducing zones of the furnace, but is reoxidized to P_2O_5 in the upper portions of the charge or in the gas flues leading from the furnace and combines with the moisture carried in these gases to form a dense white cloud of phosphoric acid which is collected by electrical precipitation into a syrupy liquid, from which remarkably pure phosphoric acid may be readily crystalized.

The ease with which a very high purity of product is obtained has been the secret of the commercial success of this industry for it immediately gave it command of the very lucrative market for food grade acid as used in baking powders, self-rising flour and the ever-expanding field of non-alcoholic beverages.

The price per unit of phosphorus for such grades of acid is, however, so high compared with that for fertilizers that brilliant commercial success for a process in the one field does not mean that it can necessarily compete at all in the other. As a matter of fact, cheaper, suitably located electric power is needed than is now generally available.

The recently developed Liljenroth process may perhaps best be considered as a variation of the above procedure in which hydrogen is secured as a valuable by-product to help cover the expense. This is done by carefully excluding air from the electric furnace and collecting the phosphorus in the elementary state following essentially standard practice of the match industry, but with larger furnaces. The phosphorus is then revolatilized, mixed with several times its equivalent of steam and passed at some 700° C. over a suitable catalyst when it combines with some of the oxygen of the water vapor to form phosphoric acid and free hydrogen. Liljenroth proposes to use the latter for the synthesis of ammonia which latter would then be neutralized with the phosphoric acid to make ammonium phosphate as a concentrated fertilizer or ingredient thereof.

This process was tested out on a semi-commercial scale at Niagara Falls some two years ago with encouraging results. It has since been further studied in Germany with the result that one-half of the cyanide equipment of the Piesteritz plant of the Bayerische Stickstoff

Werke near Berlin is now being converted to these phosphorus furnaces and by next fall is planned to be operating on a capacity of upwards of 25,000 tons of phosphorus per year which will be shipped to the huge Merseburg synthetic ammonia works of the Badische Company, there to undergo the reaction with steam and eventually appear as ammonium phosphate.

In both the above processes, coke is the reducing agent, but the electric power may of course come either from water power as it essentially does at Anniston, or from coal as it does at Piesteritz.

There is still another possible variation of these processes which, though as yet still less developed or proven out, would if successful be even more intimately linked with the coal industry. I refer to the possibility of substituting further heat of combustion for the electric energy now used in these processes. In spite of a number of patents having appeared in the literature, little positive information was available until the Bureau of Soils[1] began experiments on a semi-commercial scale in a combined shaft and reverberatory furnace for direct production of phosphoric acid with such encouraging results that commercial firms took up further experimentation on a still larger scale. To date, no details of these latter experiments have been published, but the subject is being actively studied and experimented on, both in the government laboratories and the industry.

There is also no fundamental reason why the Liljenroth type of process should not also be operated with fuel direct in place of the electric current and this is also receiving careful study.

It is quite possible that the full commercial significance of this whole group of processes will not be realized until oxygen or oxygen-enriched air is available on a far larger and cheaper scale than in the past. This latter, however, constitutes not merely a possible but an inevitable development of the very near future, whose actual commercial accomplishment, I am firmly convinced, is far more imminent and wide reaching in its industrial consequences than is at all generally realized. A discussion of this aspect of the question would, however, lead us too far afield for the present purpose.

To sum up the possible magnitude and significance to the coal industry of such a change in practice as above suggested, we may take

[1] U. S. Dept. Agr. Bull. No. 1179, December, 1923. "Investigations of the Manufacture of Phosphoric Acid by the Volatilization Process."

the present phosphate rock production of this country at about three to four million tons per year, somewhat over a quarter of which is exported in the raw state, practically all the rest going into acid phosphate. Even should the coal requirement considerably exceed the weight of the phosphate rock there would still seem ample margin for economic success.

Finally to return briefly to the subject of nitrogen, the previous speakers have already pointed out how completely the direct synthesis of ammonia out of nitrogen from the air and hydrogen from some form of chemical treatment of coal or other fuel is coming to dominate the world's nitrogen supply.

The outstanding lesson of this whole conference is perhaps the realization that we are just entering upon one of the greatest and most fundamental revolutions in chemical technology; viz. the direct use of hydrogen and carbon monoxide themselves as reagents in the "Heavy Chemical" industries. We are just beginning to realize that the Haber-Bosch Process was simply the pioneer in this new field and the fact that even the larger synthetic ammonia plants are still devoted exclusively to the production of ammonia and its derivatives is merely because this phase of what we may term the Hydrogen Epoch in Chemistry developed first and so rapidly ahead of other phases.

As the synthesis of other compounds such as the alcohols, aldehydes, phenols and hydrocarbons develops industrially it seems well nigh inevitable that the economies of mass production and interrelation between products should bring about more and more an interweaving of the manufacturing, to say nothing of the distribution and marketing.

When this occurs it will be harder than ever to predict how far the cost of any one product may be reduced, for it then becomes to some extent a matter of bookkeeping, but we may safely assume that it will be at least as low as when the product was manufactured separately.

Only a couple of years ago, with ammonia as sulphate selling for 12 to 16 cents per pound, anhydrous at 32 to 40 cents, and crude liquor at 8 or 9, many well informed people looked upon a prediction of 5 cents for ultimate cost of synthetic ammonia at point of production, as over optimistic. Today producers are confidently laying their plans

on a basis of reaching 3 cents in the near future if indeed this has not been attained by some already.

Once such levels are reached, transportation costs will loom much larger in proportion, furnishing added incentive to turn to the more concentrated forms of fertilizers, thus again strongly emphasizing the importance of the coming developments discussed above under phosphorus. Even with all that may be expected in concentrated fertilizers, however, it is evident that a country as large as ours and with its inevitable transportation costs and widening needs for fertilizer, is going to find it nationally inexpedient to gather all or even the major part of the production into any one locality.

Thus far, our whole discussion has centered about hydrogen and ammonia as the gateway to synthetic fertilizer nitrogen. There seems to be no question but that this is to be the practical situation for at least some years to come, since even if the basis for fundamentally new methods of synthesis were to be discovered tomorrow it would, under the most favorable circumstances, probably take years for the technical and industrial development to overtake the present ammonia industry with the head start it has acquired.

On the other hand it would be strange indeed if we had now reached the final limit of expediency in processes of fixation. Where the nitrogen is wanted in the form of ammonia or its salts the margin for improvement is doubtless the narrowest but where the call is for nitric acid or nitrates there would seem to be more chance for a competitive process.

Thus in making nitric acid by way of the ammonia synthesis we first carefully separate the nitrogen from the oxygen of the air, then have to produce and highly purify hydrogen as one of the chief elements of cost and combine this hydrogen with the nitrogen. But our next step is to use the oxygen of the air to burn this combined hydrogen to water merely as a way of inducing the oxygen and nitrogen themselves to combine. In other words the production, combination and burning of hydrogen within the molecules, as it were, takes the place in a sense, of the electrical energy used in the old arc process and does it more economically. The question is may there not be other even more economic ways of inducing this direct union between the

nitrogen and oxygen of the air either by themselves or in further association with water to form nitric acid or with bases to form the nitrates. In this direction perhaps lies the greatest promise for the future of nitrogen fixation.

DISCUSSION

CHARLES L. PARSONS.* I was much interested in Dr. Jones' comparison between hydogen produced from coke by the water gas procedure and the production of hydrogen electrolytically, the cost of each and the price at which power could be used to produce it economically. It is quite customary, and I presume Dr. Jones did the same thing, in making that comparison to figure the oxygen as a waste product. That is done all over the world. It is quite natural that people should look at it that way. I did so myself until quite recently, when I had the privilege of seeing some work which I will mention in a moment. A great potential source of hydrogen, however, is overlooked when the by-product oxygen is forgotten. For example, there is an electrolyte plant in the United States today producing some 600,000 cubic feet of hydrogen a day, and throwing away 300,000 cubic feet of oxygen. That 300,000 feet of oxygen if used in a gas producer instead of air, will produce 1,800,000 cubic feet of water gas, of which of course 600,000 cubic feet is hydrogen as is comes, and the other 1,200,000 cubic feet is carbon monoxide which by the Bosch method can be converted into hydrogen. This oxygen therefore is a very cheap potential source of hydrogen. With oxygen, only one-third of the coke necessary when air is used is required in water gas production; therefore the water gas is unusually cheap. Oxygen, accordingly, should not be thrown away.

There is a plant projected in Europe which will waste, according to their present plan, something like 4,000,000 feet of oxygen a day. That 4,000,000 feet of oxygen could be used with steam to great advantage in producing water gas and hydrogen therefrom in a continuous converter.

Also with reference to your Muscle Shoals situation, this is an interesting point. It certainly looks as if the sublime wisdom of our legislators in Washington will require some of that power to be used for fertilizer. If so, the only way to proceed at the present time, in my opinion is to electrolyze water. If instead of the electrolysis of all the water necessary to meet the Government requirements, whatever they may be, they only produce one-fourth of that amount, they can save three-fourths of the power and therefore have more power for other uses.

Now it was my good fortune about two months ago to be in Toronto and to see a small furnace which had been operating this

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way. Oxygen had been blown with steam and the converter had worked smoothly producing a high grade water gas. The operation could be made automatic. I was told that if the steam was cut off by a valve the heat of the furnace would go up immediately. On the other hand, by increasing the steam it was quite possible to drown out the action completely. The operation might be controlled by a valve operated by a thermostat.

I was very much impressed with its relation to the nitrogen fixation situation, so I wrote to Mr. Stuart, consulting engineer in Toronto, Canada, who was doing the work. As it has an important bearing on this subject, his answer will prove interesting and pertinent to this discussion. Mr. Stuart says:

"By means of a continuous oxygen-steam blast injected into the gas producer, it has been estimated by various writers that one ton of bituminous coal will gasify at about 95% efficiency and produce over 60,000 cubic feet of 400 B.t.u. gas. If the oxygen were made electrolytically and hydrogen were added to the gas, the output becomes 85,000 cubic feet of 380 B.t.u. gas. Such production is, of course, far beyond anything possible without oxygen.

"Furthermore, the volatile matters of the coal, released in an atmosphere of water gas and conveyed immediately into cooler zones, are better preserved than would be possible in externally heated retorts.

For such reasons the oxygen process perhaps represents the ideal in 'Low Temperature Carbonization' with 'Complete Gasification of residues,' and it has been said that, when cheap oxygen is available, this process will be used in city gas plants.

"Where water gas is required for such processes as the syntheses of ammonia, methanol and oil from coal, the gas producer may be operated as above described on a coke charge. The materials enter and leave the producer cool so that almost 100% gasification is effected. Therefore, if to the output of this producer electrolytic hydrogen were added, the total production becomes almost three times the amount possible when air is used to gasify a given amount of coke. Consequently a saving of almost ⅔ of the coke is effected together with equivalent savings in fixed charges and cost of operation.

"By regulation of the oxygen-steam rates, the gas analysis may be held constant within any desired limits. This also is an advantage over the use of air where temperatures constantly change and where nitrogen and larger portions of carbon dioxide become mixed with water gas.

"By increasing the steam rates, the producer temperature might also be held lower so as to yield greater amounts of hydrogen for syntheses.

"Since both oxygen and hydrogen can be used simultaneously in the gasification of coal and coke, the electrolytic process becomes very attractive where power is of low cost. This is especially true where hydrogen and water gas can be used for syntheses.

"In one concrete example, one plant in the United States using quite expensive power is now wasting some 300,000 cubic feet of electrolytic oxygen daily and, in another example, a plant is projected in Europe where 4,000,000 cubic feet of electrolytic oxygen per day will be wasted. Such oxygen could be converted into six volumes of water gas by operating a gas producer charged with coke.

"For the electrolysis of water, there is undoubtedly available a good deal of undeveloped water power. But in addition to this, there is large off-peak capacity on operating plants. In Canada, for example, it is estimated that such unutilized capacity would be capable of producing about one hundred thousand million cubic feet of oxygen and hydrogen per year.

"Theoretically, one K.W. hour is capable of generating about 16.44 cubic feet of the two gases and one H.P. year is capable of producing 108,000 cubic feet.

"As a result of recent developments, it is now possible, with the most improved types of cells, to obtain yields up to 15 cubic feet per K.W. hour in apparatus which is entirely automatic and where all costs, other than power, need not exceed 5¢ per thousand cubic feet of gas. When power charges are added, the gas cost increases about 1¢ per thousand for each $1.00 per H.P. year—so that oxygen and hydrogen costs may vary from 10 to 30¢ per thousand under favorable conditions.

"There are many examples where large blocks of power are used to make hydrogen and where oxygen is now wasted. In these, one H.P. year generates at best some 65,000 cubic feet of hydrogen, whereas, if the oxygen were also used, the production would be increased by some 200,000 cubic feet of water gas also available for syntheses and with a saving of some ⅔ of present water gas costs.

"Such facts indicate that the electrolysis of water is a process holding much promise in the utilization of coal and which should command immediate efforts to utilize oxygen."

CAPTAIN DAVID SHIELD.* My viewpoint on the use of coal is entirely different from that of you gentlemen whom I have heard speak;

* Farmer, Shields Post-office, Allegheny County, Pa.

very radically different regarding some of the uses for coal. I have been investigating and experimenting with coal as a valuable substance for a plant fertilizer for forty years; and my work has given such satisfactory results that I feel it important to call the Conference's attention to it.

One of your speakers says that the farmer will not buy fertilizers; that he cannot afford to do so. Their price is too high considering their value to the crop and no appreciable value to the land's productivity. They are not a plant food. It is not only the cost that the farmer objects to, but he is dissatisfied with the results and the condition in which his ground is left. I grant that some farmers admit that these elements are beneficial on some soils, but their continued use is harmful, especially in a dry spell of weather, as they burn the ground.

Believing that coal is of vegetable origin, I have worked years to get it into a useful state or condition for fertilizing crops. Now after forty years working on various crops in the growing season and on potted plants in the green house in the winter time, I can show results proving that my theory that coal has value as a fertilizer is correct.

To obtain a proper fertilizer I grind the coal to a fineness that will pass through a mesh of 15 or 20 to the square inch. Then I mix with it subterranean salt water in the proportion of one pound of water to four pounds of coal. The subterranean salt water is found 1,000 or more feet below the surface. It contains soluble elements taken out from the different stratas of the earth: chloride of sodium, chloride of calcium, chloride of magnesium, iron (certain forms), sulphur, alum.

This mixture is put in a vessel and heated. When it reaches a temperature of 110°F., signs of fermentation appear, increasing greatly until a maximum of 170°F. is reached. The heat is then stopped and the mixture is held in that condition from 18 to 24 hours. At that time the mass has increased in height (the only way it has to expand visibly) as much as 33% or one-third of its original height.

Clay is now added and mixed with the coal. This is put aside and has to go through a slow process of amalgamation, sometimes taking six weeks. At the end of that period the mixture has become uniform. The ratio of clay to coal is not important. Three-fourths of the mixture may be coal or three-fourths of it may be clay. Good results have been attained at the rate of three-fourths clay and one-fourth solids of the salt water and coal. About 460 pounds of coal and 40 pounds of solids from the subterranean salt water are used in making a ton of fertilizer.

As a farmer I can say that this fertilizer is fitted to be used on any land for any sort of vegetation; being vastly superior in all ways to chemical-made fertilizers.

Forty years ago, as a farmer, I was much impressed with this view of the use of bituminous coal. After thirty years of persistent, continuous and fascinating work, I succeeded in proving that the theory was a fact, by applying to a piece (85% of an acre) of rather poor ground 700 pounds of this treated coal (humus) sown broadcast by hand, covering five quarts of new and fresh timothy seed sown thereon on the 2nd of April, 1913. It grew an astonishing crop of grass, yielding nearly six thousand pounds of dry hay. The next year the same piece of ground yielded a very large crop of field corn (the record is lost). The next yield from the same field was one hundred ninety bushels of white potatoes and the next year (1917) yielded forty-two bushels of clean rye (threshers' measure), all from one application (in 1913) of 700 pounds of this "humus." The United States census report shows the average yield of rye twelve bushels to the acre.

This test is one of many (over two thousand recorded) other yields and tests of similar significance of the correct use to be made of coal (humus), peat, lignite, carbonaceous substances, in conjunction with the clay from which the coal (humus) as vegetation grew.

Walter S. Landis.* We owe to our hosts and fellow attendandts from the other industries not only our thanks for the wonderful program to which we have listened but a frank and faithful statement of facts surrounding our own nitrogen industry and its relationship to theirs.

Many years ago when the fixation industry was in its infancy it was described as "the art of taking money out of the air." I do not want to leave that impression with you without further commentary. Excepting for the older companies established in this industry before the world war I doubt if many of the later projects could carry their capital cost on a reproduction basis as fertilizer producers. As we have heard fertilizer nitrogen is sold at the bottom of the price index. We all know we are paying for labor, power, raw materials at or near the top. In spite of this Dr. Cottrell and the other speakers have mentioned the growth of the industry in number and size of plants.

What is the true significance of this? Is this a normal growth based on private capital earning a proper return as are the coking plants that are building today? If one examines into these newer plants he will find some surprising facts not brought out by the speakers on this afternoon's program.

England has such a plant making synthetic ammonia from coal. I question if it is a profitable undertaking if based solely on private capital, and reproduction costs. Germany has several plants of like character. They were built by the Government and turned over to private operation before the collapse of the mark. I wonder if they

* Vice-president, American Cyanamid Co., New York, N. Y.

could pay their way if based on a normal capital structure and a fertilizer market. France built several on different systems as war emergency plants. And her currency is depreciated greatly since then. I am inclined to believe that some of them are hardly self-supporting without some form of artificial assistance or subsidy.

The prewar developed plants built and operated as private undertakings all seem to be successful if an earning's statement is a fair measure of success, but most of them have a very low capital cost further reduced by write-offs and extensions from earnings. This is in marked contrast with the later developments particularly in this country where none of these late comers have dared enter the fertilizer markets. As stable fuel consumers let us not be too enthusiastic about these new comers here at home.

As a matter of fact many of these foreign plants have been erected either as war emergency sources of nitrogen or as preparedness measures for the next conflict. Europe has learned Chile is too far away when the blow falls. And these plants will be maintained in operation irrespective of the relationship of market prices to costs of production, for a preparedness plant is only such when it has a trained operative force behind it. While none have been built for the express purpose of making fertilizer that is their only peace time outlet.

Now the coke oven is the cheapest producer of nitrogen we have. On a strict competitive basis it would survive the longest in a price war, but we are not considering such a basis. Future fixation ventures in this country must take this into consideration, and before embarking in this field must have some solution of the present problem of over production of ammonia. We have heard one proposed solution today which I consider only part of the answer. The solution offered was to increase the consumption of fertilizer by using more on our farms.

It must be remembered that increased use of fertilizer results in increased production and lowered costs. But unfortunately increased production with us causes prices to drop, as evidenced by the plight of our wheat and cotton farmers this year, faster than fertilizer usage can decrease costs of production. Had the cotton farmer used another hundred thousand tons of nitrogen, I don't know where the price of cotton would have dropped. The real economic remedy is a brutal one it is true, but must be faced. If we should move half our farm population to the cities and make consumers of them, and then teach the remainder the proper use of fertilizer, we can increase nitrogen consumption in a sound and economic manner. Or we might find some system of putting only part of our farm land under intensive cultivation and forest the remainder. This will have the same effect on increasing fertilizer consumption. Advocating under present conditions the use of more fertilizer alone does not wholly solve the problem.

It might interest our coal producing friends as to just how much coal these fixation plants consume. We all know that it takes about

400 to 500 tons of coal to produce a ton of nitrogen by the high temperature coking process. In the Cyanamid process if electric energy, as from a hydro plant is available, 3 tons of coal and coke will fix a ton of nitrogen. If the electric power is developed by steam we must add 6 to 7 tons more of coal for a large modern plant. In the synthetic ammonia process producing its hydrogen from coal and its power from steam a total of 5 to 6 tons of coal is required per ton of nitrogen. In other words depending on the process a maximum of 10 tons of coal per ton of nitrogen fixed would place a very small draft on the coal miner if we doubled our nitrogen consumption via fertilizer in this country. It would take but a few million tons at most. I believe that for sometime to come the by-product coke oven will be increasing the production of nitrogen faster than the synthetic plants, if the latter have to stand on their own feet at present construction prices.

JOHN V. FREEMAN.* As you know, the Government has provided money for experimental work in oil shale distillation in the neighborhood of Rifle, Colorado, I think it is. I would like to ask as a matter of information, should this method prove successful, would it be important as a source of ammonia?

HARRY A. CURTIS. I know ammonia is produced in this process and can be recovered, but I do not know what the quantity might be.

CHAIRMAN A. C. FIELDNER. I cannot give the figures myself as to how much we can get from the oil shale, but there will be figures available from this distillation plant at Rifle, Colorado, because this is one of the purposes of this experimental plant, which is just getting fairly under way. The figures are not available yet.

KENNETH ALLEN.† Mr. Brand mentioned the depreciation of soil. A friend of mine in Chicago was so interested in this subject that he would test the matter out by taking bores along the Illinois Central Railroad, then on the adjoining soil which had been under cultivation for fifty years. He made those bores and found eighteen inches of soil on the right of way as against nine or ten inches outside. He considered that a matter of very great importance, and he wrote a paper in which he expressed the belief that where soil was being eroded from the corn belt it was very largely because the land was being cultivated ahead of the heavy downfalls of rain in June and July in this part of the country; and he believes that the cultivation of alfalfa would very likely correct that, alfalfa having deeper roots that bind the soil, whereas the corn will not do that. Furthermore, he has experimented and tried alfalfa; alfalfa cutting two crops a year, where corn cuts only one. The soil if eroded, if washed out, cannot be replaced, even by fertilizer. I understand it is the theory that disintegration of the rock forms the basis of the soil that is used for

* U. S. Steel Corp., New York, N. Y.
†Sanitation Engineer, Board of Estimates and Apportionment, New York, N. Y.

raising plant food, and unless we have it, no artificial fertilizer can take the place of that soil when once gone. He thinks in southern Europe that has already taken place, in Italy and Spain, where the soil is quite poor and has to be intensely cultivated; whereas, in northwestern Europe it is more like in New England here, the rainfall is more moderate and the soil doesn't wash off.

WALTER S. LANDIS. A matter concerning domestic nitrogen production that has not been touched upon here, fortunately presents a picture which does not confront the economic conditions existing in the fertilizer industry as pictured to us by a previous speaker. Producers should not lose sight of the fact that there is almost as much nitrogen used in the chemical industry as in the fertilizer industry, as for example in the production of dyes, explosives, cleaning compounds and refrigeration. Fortunately it is not usual for these industries to all get out of gear in the same year as our agricultural industry. There is usually a year or two difference in the cycles. Therefore, we have here an enormous consuming market for ammonia compounds that is absolutely untouched in this country by domestic producers. While the production of nitric acid from ammonia compounds may be wrong technically and chemically as Dr. Cottrell has pointed out, nevertheless, it is a highly profitable operation.

It is quite possible today to take the cheap ammonia and convert it into the high priced nitric acid and nitrate compounds. The German industry in particular has based its development on insuring customers for its oxidized ammonia in the various branches of the chemical industry and there is practically not a pound of nitrate of soda imported into Germany today. In other words, they are running their chemical industry on nitric acid produced from ammonia. This is something that we have given little attention to in this country and I want to impress upon you that there are other markets for our fixed nitrogen than the fertilizer industry.

R. S. MCBRIDE.* There has been quite a little discussion in this conference regarding the contribution which the by-product industries are making to the nitrogen situation, supplying ammonia, and sulphate, which all come from coking coal. I would like to point out a thing not mentioned at this conference and that is, the counter-effect of the production of nitrogen from other sources, or the effect of the nitrogen industry, on the by-product industry. The large production of nitrogen which has come on synthetic methods has lowered the price of nitrogen from about three cents a pound for ammonia sulphate to about two cents, in round numbers. This produces two important effects, one in steel and one in the gas industry, not commonly known. You know in the steel industry the cost per ton of pig iron produced, is the difference between the gross expenditure and the income from by-products.

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By lowering the price of ammonia sulphate by one cent a pound, it has meant thirty to forty cents per ton of pig.

In the city gas business the effect has been even more marked, because there its equivalent is greater per unit of gas. It sometimes amounts to as much as five cents per thousand cubic feet of gas.

This reverse effect of the nitrogen industry on the gas industry and coke industry must not be forgotten, because every time you lower the price we increase the price of the other two commodities and coke and gas would have to carry the difference between gross cost and income from by-product.

THE ECONOMIC ASPECTS OF THE CONVERSION OF COAL INTO SMOKELESS FUEL

By Horace C. Porter
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Two lines of attack with which we may combat the smoke evil seem to be offered: first, to extend the use of good methods and good equipment in the burning of raw coal; second, to manufacture and burn more of "smokeless" fuels—those fuels which cannot, except with difficulty, be burned so as to make smoke.

Both of these methods entail some initial expense to the consumer, although he regains his outlay, and often more, in the end. The first method has, up to the present, required the lesser outlay and, therefore, has been used more than has the adoption of prepared smokeless fuels.

Psychology, as involved in this very matter of initial expenditure and intangible returns, enters prominently into the question of smoke abatement. The fuel consumer hesitates when he is confronted with a higher bill for his year's supply of thermal units, or an additional outlay for improved plant, incurred chiefly to enable him to avoid smoke, dust and dirt. This hesitancy can be and is being overcome among the larger consumers—the railroads, the utilities and the manufacturing industries—by the force of public opinion, and by the realization of an ultimate profit to be derived from increase of operating efficiency and the benefits of a clean, healthy atmosphere. The growth in centralization of power production, the increased use of gas in industry, and the gradual replacement of the steam by the electric locomotive, are already doing much to abate smoke.

To the small consumer, however, the average householder or manufacturer, who finds it necessary to take account closely of initial outlay for fuel, the appeal for smoke abatement is quite generally in vain, if it means an initial burden of added cost. In order to go far

with domestic smoke abatement among the masses a smokeless fuel must be offered which carries only a small margin of cost, if any, above that of the raw fuels available.

We burn annually in America, without serious production of smoke, at least 200,000,000 tons of fuel—coke and gas (figured to coal equivalent), anthracite, and much of the central station coal. This is two-fifths of our total annual consumption (excluding metallurgical coke, exported and bunkered coal), and is thus a very respectable figure, showing that we are not entirely abandoned to a mad pursuit of industrial profits, neglectful of the common welfare.

But in the 300,000,000 tons of coal that are yet producing smoke in the railway locomotives, the host of small power plants, the metal-working and chemical plants, and in the numerous domestic fires—collectively of importance—we are confronted with a serious economic problem, especially menacing in those fast enlarging sections where bituminous coal is practically the only available raw fuel.

The question arises, therefore: Can we hope to solve the smoke problem for these sections by offering them at reasonable cost a smokeless fuel prepared from bituminous coal? Or must they depend chiefly on the use of improved burning equipment, central station power, and greater care in operation of furnaces?

It has been estimated that the larger sources of smoke in the average urban community where soft coal is burned are the railroad locomotives, and the small power plants serving individually the small factories, hotels, business blocks, etc. If a smokeless fuel suitable for the needs of these consumers could be offered them at a price little if any higher than that of coal and could be supplied continuously in sufficient quantity it is probable it could be sold, and good progress thus made in smoke abatement.

The large central power station is not ordinarily now an offender in smoke production, having mechanical stoking equipment and boiler settings capable of operation without smoke. These stations are doing much to lessen smoke also by increasing the centralization of power production, enabling the abandonment of many of the smaller isolated plants.

There will continue to be needed, however, an improved smokeless fuel for the domestic fires, the railroads, and the small power and heating plants.

Coke made in high-temperature ovens we have already in limited quantity. It has established itself successfully in many communities as a high-grade smokeless fuel commanding a high-priced market where anthracite is not readily available. Owing to the high costs of by-product ovens and equipment a plant must sell its coke output at an average price well above that of the coal carbonized, and dispose at the same time of gas and by-products advantageously. Therefore, as a household and general fuel, coke cannot hope to be universally adopted in communities where bituminous coal is to be had cheaply.

In order to make such sections 100 percent smokeless it will be necessary to devise a process that will give them a low-priced prepared fuel to compete with bituminous coal on a close margin of price and of such quality as to meet the demands for steaming capacities and other firing qualities set up by bituminous coal.

Whether low temperature carbonization of coal can do this in the future remains to be seen. It has not yet attained the goal.

The necessary margin as an investment to investors of capital has not yet been shown. The margin that does appear with some processes under favorable commercial conditions is still too small to give the necessary impetus and to overcome the risks of market fluctuations, irregularities of operation, and other contingencies.

A point in this connection that is often lost sight of, or underestimated, is the loss of heat units—that is, available heat energy—through the carbonization process. If we have a net yield of 67% semi-coke (after providing for firing of the retorts) and this material, owing to higher efficiency, has, say 10% more of available heat per pound than has the coal, we still have lost 25% of the original heat in the coal. Gas and tar we place as by-products.

It is of value to set up a balance sheet in simple form.

Gains:

Tar, 24 gals., @ 6c	$1.44
Gas (800 B.t.u.) 32 "therms" (of 100,000 B.t.u. each) @ 4½¢	1.44
	$2.88

Losses:

25% of heat in coal	$1.12
Margin for profit and contingencies, 20% on invested capital	.80
Balance, for costs of plant investment and operation	.96
	$2.88

On this basis, it is readily to be seen that costs of conversion must be brought to $1.00 per ton of coal or lower, if the smokeless fuel

produced is to sell at the same price as coal. With an enhanced value, however, in the semi-coke such as, say, to command 20% margin in price, there would be available $1.50 for conversion costs, instead of $1.00.

The problem presented, therefore, is three-fold:

(1) To lower the cost of conversion, by engineering development of the processes, to a point less than $1.00 per ton of coal, under existing commercial conditions;

(2) To establish a sufficiently enhanced value in the semi-coke, ton for ton, as compared to the coal from which made, to enable a ton of coke to bring a return at least equal to the cost of the coal used in making it;

(3) To discover commercial applications of the special tars and gases produced by these processes which will enhance their value above that of the now traded-in coal tar and gas.

It is likely that all of these phases of the problem will need to be solved in some degree before the pre-treatment of coal by low temperature carbonizing will have important commercial success. A big advance, however, along any one of these lines would no doubt exert a strong impetus for the promotion of projects in this field.

As bearing upon improved efficiency and smokeless operation of boiler furnaces there is much interest being manifested now in the possible beneficiation of coal for boiler firing by pre-drying and partial carbonizing. In this way may be found a considerable impetus for low-temperture carbonization as applied to certain types of coal.

As Runge[1] and others have pointed out, the net heat units available per pound under a boiler may be increased by 10% or more through carbonization of a coal carrying, say, 6% moisture. The stack losses in the items of moisture of the fuel, moisture from burning of hydrogen, and heat of the dry chimney gases resulting from excess air supplied are materially reduced by the pre-carbonization treatment. This advantage may be found to lead to an important gain in burning, say, the Illinois type of coal.

Furthermore, it is reasonably to be expected that a boiler furnace may be pushed to higher capacities without reduction of efficiency or the making of smoke through the use of a free-burning dry and tarless fuel such as well-made semi-coke, than are possible with the corresponding raw coal. This advantage would lead thus to a reduced cost of furnace and boiler equipment.

Direct-connected, continuously operated, pre-carbonizers on a boiler furnace would give the added advantages of sensible heat in the fuel and the minimizing of rehandling machinery or labor. But there are practical difficulties here arising from the necessity of rotating the boiler units in a plant so as to keep one or more out at all times

(1) W. Runge, *Coal*, April, 1926, pp. 196-201.

for cleaning and repairs. Whether the carbonizers, if direct connected, could be shifted as required from one boiler furnace to another and thus maintain the continuous operation necessary for good results constitutes an engineering problem well worthy of attention. At any rate, here is a field that presents possibilities of important advantages to be gained in low-temperature carbonization and enhancement thereby of the unit value of the fuel.

Under the head of by-product possibilities the very rich gas obtained from low-temperature carbonization is worthy of consideration as an important source of revenue. A gas of 800 to 900 B.t.u. per cubic foot, not so constituted as to cause trouble with condensation, should be of high value as an enriching agent to mix with a lean, low cost base for city supply. Let us assume that a station of 200,000 to 250,000 k.w. capacity, such as are operated now on coal in several of our large cities, should find it practicable some time in the future to pre-carbonize 1,000 tons per day out of its total coal consumption. Enough 800 B.t.u. gas could thus be made to mix with 3,500,000 cubic feet of blue water gas and make 7,000,000 cubic feet of 525 B.t.u. city gas, saving $1,000 worth or more of gas oil. Such a possibility of by-product gas from a single station is a feature of low-temperature coal carbonization that may some time challenge attention of the gas utility men.

In any consideration of possible future developments in the making of smokeless fuels from coal the rapid growth in the use of manufactured gas, both domestic and industrial, must not be overlooked. Gas is an ideal smokeless fuel, and offers many other advantages and economies which act to counterbalance in important degree its added unit cost. It is reasonable to look forward to a future lowering of the price of gas, in relation to coal prices, as changes in requirements of heat unit standards and in the drawing up of rate structures are brought into play, and large central stations use improved and less costly methods of manufacture made possible by lower requirements of B.t.u. standards.

It may be expected therefore that coal carbonization for the production of gas will extend itself rapidly, and that methods for gas manufacture will more and more be used that produce at the same time practical smokeless solid fuels, capable of satisfying the conditions demanded by consumers. Whether high-temperature or low-temperature carbonizing methods will have the larger share in this developement cannot be prophesied now. It is not reasonably to be voted, off-hand, as has been done by some writers, that low-temperature carbonization is inherently wrong in principle and offers no economic prospects of success. It appears to be a question merely of reducing costs or of raising form-values in the products, and these things are not beyond the bounds of possibility.

In conclusion and summary we believe the pre-treatment of coal

for making smokeless fuel will go ahead along all three lines, high-temperature coke, low-temperature or "semi" coke and gas. Each will find a field to which it is peculiarly fitted and in which the consuming public will learn eventually to appreciate its virtues. Before prepared smokeless fuels, however, can have wide general application, their cost as related to that of coal will have to be lowered through simplification and improvement of processes and enhancement of by-product values. New systems of pre-treatment of coal, such as low-temperature carbonization, will obtain a sure footing commercially only when they can show by lessened costs and better by-product values a good margin of profit to induce the investment of capital. Their best chance is in the field of the lower grade, higher oxygen coals of the midwest where a greater enhancement of value may be obtained, as between a low-priced raw coal and a high grade conversion product.

Addenda

As bearing on the balance sheet figures shown on page 601 an article has appeared since submitting this paper, in the British journal, "Fuel in Science and Practice," November, 1926, pp. 510-11, by Philip C. Pope, on "Economics of Low Temperature Carbonization."

On an admittedly theoretical basis, that is, without actual commercial operating data, he assumes—

Plant of 500 tons capacity (coal per day),

Operating 300 days per year,

On washed slack @ 12s. 6d. ($3.02), less 7% for moisture or a net cost of 11s. 7½d. ($2.79),

Plant located at mine mouth, to secure cheap coal, and no charge for rents; therefore no outlet for gas.

Only 62½% yield of coke, presumably allowing for loss of breeze and dust.

An average sale price for this coke of 20s. ($4.84) per ton, or a return on each ton of coal of 0.625 times $4.84 or $3.02, thus providing a gain of 23c on the coal instead of a loss of $1.12 as in my table, page 601.

He expects returns on by-products (only tar and "spirit") of 7s. 9d. ($1.86) per ton coal.

His total gain is therefore $2.09 per ton coal ($1.86 plus 23¢) to cover both operating and investment costs, profit and contingent fund. This compares with my estimated balance available for these same purposes of $1.76 when the coke is assumed to be only of equal per ton value.

Out of his balance of $2.09 available for costs and profit, he estimates 4s. 1.2d. (99¢) as required for operating expense, and thus is left with a balance of 4s. 6.3d. ($1.10) for "capital expense and dividends." On the basis of a plant investment of 200 pounds sterling ($970) per ton of coal throughput per day, he divides this balance into 61¢ for capital expense (19% on capital) and 49¢ for dividends (15% on capital).

SMOKELESS FUEL

By O. P. Hood
Chief Mechanical Engineer, U. S. Bureau of Mines.

According to the program, the subject assigned to me is "Smokeless Fuel." As it got to me in Washington, it was "Smokeless Coal." So my paper is on "Smokeless Coal." That leaves the larger and the most smokeless end of this subject for some one else to treat properly. If I were to treat it, I would look forward to that time when the domestic consumers in cities would use gas almost exclusively instead of solid fuel. When that time comes we will have smokeless cities, probably.

It has seemed to me that the present oil burner development is a step in that direction, that they are preparing the ground for the ultimate use of gas in our homes. My paper, however, as I have written it, is on smokeless coal. One other word of explanation: this audience that knows so much about coal should have presented to it a much more technical poper than I have prepared, but I have taken this opportunity to speak, not to you but through you, to that larger audience that knows so much less about coal that they are confused over this term, "Smokeless Coal." People interested in smoke abatement write to the Bureau of Mines very frequently, showing considerable confusion in their understanding of this term.

"Smokeless coal"—this innocent phrase, seeming so simple, is charged with various meanings. To the layman unlearned in the ways of commercial nomenclature or the views of the combustion engineer, the phrase means just what it says, namely, a fuel which burns without smoke under the simple combustion conditions that he supplies. The fuel must never smoke, or he may possibly broaden his definition to include, in a Gilbert and Sullivan sense, those coals that "hardly ever" smoke. He feels justified in this view, for he knows about such fuels. A large part of our people know about the smokeless burning of anthracite, and a smaller part know of similar service from coke.

To the dealer in coal the phrase has a different meaning. It has been applied as a trade name to our semi-bituminous coals which smoke

but little because of their relatively low volatile content. The commercial advantages of the classification are such that the upper limit of volatile matter has been stretched to include coals that are smokeless, by courtesy only, when judged by the anthracite or coke standard.

To the combustion engineer the phrase raises a query. Is it the coal that should be called smokeless, or is it the combustion conditions supplied by furnace, grate and draft that should be called smokeless? To him all coals are smokeless, provided he be not limited in his method of burning. Our highest volatile coal can be burned smokelessly if conditions are properly adjusted to the characteristics of the fuel.

The term "smokeless coal" can, therefore, be considered from several points of view. If we restrict the meaning to those coals which can hardly be made to smoke with the most thoughtless handling under bad combustion conditions, then we are practically limited to those classed as anthracites, and to other fuels having a similarly high ratio of fixed carbon to volatile matter. With volatile matter removed by heating, the remaining char or coke of all of our fuels may be made to come well within this range. The anthracites have from 3% to 7% volatile matter, which burns with a short blue flame without smoke. Good metallurgical coke has but 1% to 3%, while heat treated fuels of other sorts leave residues with amounts of volatile ranging from 2% to 15%. Only a relatively few of our coals when heat treated according to our best present knowledge retain physical characteristics of coherence and strength that make them immediately desirable as a commercial fuel. To give strength and coherence and acceptable form value, briquetting is resorted to. The usual binder, unfortunately, adds smoke producing material, so that a second heat treatment is required to produce a really smokeless fuel for domestic use. The Carbocoal produced at Clinchfield was of this type, and its quality left little to be desired. In the future we can expect an increasing number of manufactured fuels in briquette form made of coal distillation residue with a pitch binder, and rebaked at a sufficiently high temperature to reduce the volatile matter below 8%. We may expect among these, worthy competitors of anthracite in the field of a real smokeless fuel. They will have an advantage over coke in being dense like anthracite, as free from breakage, and requiring as little thought in firing. Char made from our lower rank fuels, such as lignite, is apt to be high

in ash; but a smokeless fuel can be produced from them which may in time find a market. Since the processes can be widely varied as to temperature and length of treatment, we may expect a corresponding variety of char products that must be tried to determine quality. The kindling and radiant properties of cokes vary so that some will have special advantages. Good coke properly sized and handled makes an excellent smokeless fuel for domestic use, but it requires a little more intelligent handling than anthracite. Tar kettles, contractors' boilers and steam shovels usually resort to coke when compelled to abate a smoke nuisance.

If we consider the phrase "smokeless coal" as a well established commercial classification we have to consider an entirely different class of coals and a qualified meaning for the term smokeless. Our country affords coal of almost any carbon-volatile ratio—semi-anthracite from 6 to 10, and semi-bituminous from about 3 to 6. We have comparatively little semi-anthracite, but large quantities of our best coals are classed as semi-bituminous. The term smokeless was first applied to those having, say, less than 20% volatile, but of late it has been applied to the full classification of semi-bituminous coal, some having 27% volatile. The coals of this class burn with a short yellow flame, and may smoke about in proportion to their volatile content. They are in general friable coals, easily broken, so that when ready to place on a fuel bed there is apt to be a large per cent of very fine coal which tends to accentuate the smoke trouble by reducing the flow of air through the fuel bed when it is most needed. In the use of these coals the point is strongly accented that the quality of smokelessness is very much a function of furnace design and firing methods. Plants that have difficulty in meeting the requirements of a city smoke ordinance can frequently get by by selecting a coal with a few per cent less volatile matter. One plant with small return tubular boilers set for anthracite coal, but burning semi-bituminous coal of 21% volatile, too frequently exceeded the smoke limit; but with coal of 17%, together with considerable care, the limits were not exceeded. This raises the whole question of what is meant by "smokeless" in this sense. It is obviously a relative term, and its absolute value will depend much on the community habits. Coal of this type used in a bituminous district has considerable reason to be called smokeless by comparison. Used in an anthracite district, experience will vary according to the grade of coal and the skill used. In domestic service, with careful firing, the smoke is usually kept below an amount considered objectionable. The point should

be made that the claim to smokelessness for this group is justified in direct proportion to the skill used in satisfying rather modest requirements of furnace design and firing methods, and in inverse proportion to the volatile content ranging from about 16% to 27%. One way of determining the practical smokelessness of such a group would be to discover whether towns using such coals exclusively feel the need of smoke abatement efforts. The city of Washington comes near being a semi-bituminous town. In 1917, 34% of the coal used was anthracite, 3% bituminous, and the remaining 63% semi-bituminous of about 19% volatile matter. It can be said that Washington is on the edge of having a smoke problem. In that year about 264,000 tons of volatile matter came from the coal that was burned in the district. About 7½% of this came from coal having over 20% volatile. The smoke problem can hardly be laid entirely to this 7½% of bituminous smoke. The belief is, however, that a satisfactory condition could be maintained by a reasonable effort to see that new installations were such as could be operated smokelessly, and that there was given instruction and supervision of firing methods. Smokeless operation is much more easily attained with these coals than with the high volatile long flaming bituminous coals. They are, therefore, an important element in smoke abatement efforts.

In point of quantity West Virginia is the most important producer of semi-bituminous coals. There are three principal fields along the eastern side of the State: Pocahontas (including Tug River): New River (including Winding Gulf); and the Upper Potomac field in the northeastern corner of the State.

The principal seams worked in the Pocahontas and Tug River districts in McDowell and Mercer counties, West Virginia, and extending into Tazewell County, Virginia, are the Pocahontas Nos. 3, 4, 5 and 6, War Creek, Davy Sewell and Welch. The coals produced from these fields are comparatively uniform, being generally low in ash, sulphur and other impurities, and high in heat value. They are excellent for steam and domestic use, and when mixed with a higher volatile coal are adapted to by-product coking. Although quite friable and breaking badly when subject to rehandling, this factor does not detract from the inherent heating value of these coals.

Between the years of 1908 and 1922, the Bureau of Mines made over

a thousand analyses of delivered coals from these districts, the average analysis* being about as follows:

Moisture	2.7%
Volatile matter	18.5%
Fixed carbon	73.9%
Ash	7.6%
Sulphur	0.6%
B.t.u.	14,051

Directly north of the Pocahontas district and lying chiefly in Wyoming, Raleigh and Fayette Counties, are located the Winding Gulf and New River districts. Here the principal seams mined are the Beckley, Fire Creek, Sewell and the Pocahontas Nos. 3 and 6. These coals closely resemble the Pocahontas coals in chemical analysis. Like the Pocahontas coals, the New River and Winding Gulf coals are highly regarded for steam, domestic and by-product coking purposes. The average analysis of delivered coal from these fields is about as follows:

Moisture	2.2%
Volatile matter	18.6%
Fixed carbon	73.9%
Ash	7.5%
Sulphur	0.8%
B.t.u.	14,144

The Upper Potomac fields of West Virginia are located in Grant, Mineral and Tucker counties. The seams mined are the Upper Freeport, Pittsburgh and Bakerstown. These coals average somewhat higher in volatile matter, sulphur and ash, and correspondingly lower in heat value than the semi-bituminous coals from the southern part of the State. They are considered excellent steam and domestic coals. Analyses of delivered coal show the volatile matter varies between 15.7% and 24.5%, sulphur from 1.0% to 2.2% and ash 6.5% to 16.8%. The average analysis of delivered coal is about as follows:

Moisture	3.0%
Volatile matter	20.6%
Fixed carbon	69.2%
Ash	10.2%
Sulphur	1.3%
B.t.u.	13,537

*Analyses of Samples of Delivered Coal, by Ned H. Snyder, Bureau of Mines Bulletin, No. 230.

All of the commercially valuable coals of Maryland are semi-bituminous, and since they closely resemble one another both in analysis and structure they may all be considered together. Mining is confined to a comparatively small area in the western part of the state in Allegany and Garrett counties. This is an extension of the semi-bituminous field in northeastern West Virginia, and has the distinction of being one of the oldest coal mining districts in the country. The seams worked are the Barton, Waynesburg, Tyson, Pittsburgh, Lower Bakerstown, Piedmont, Upper Freeport, Lower Freeport and Upper Kittanning. Analysis of delivered coals from Maryland show volatile matter ranges from 15.8% to 21.8%, sulphur 0.7% to 3.3%, and ash 6.8% to 18.1%, with an average analysis about as follows:

Moisture	2.3%
Volatile matter	18.9%
Fixed carbon	71.5%
Ash	9.6%
Sulphur	1.2%
B.t.u.	13,768

The semi-bituminous coals of Pennsylvania are located principally in Bedford, Cambria, Center, Clearfield, Fulton, Huntington and Somerset counties in the central part of the state. The coal is produced chiefly from the Lower and Upper Kittanning, Lower and Upper Freeport, Pittsburgh, Kelly, Barnett and Fulton seams. While much of this coal closely approaches the southern West Virginia coals in matter of quality, some of it is inferior. Analyses of delivered coals show that it ranges from 0.6% to 3.1% sulphur, from 6.1% to 17.5% ash, and from 15.2% to 25.8% volatile matter. The average analysis* of delivered coals from Cambria, Clearfield and Somerset counties is about as follows:

Moisture	2.3%
Volatile matter	19.3%
Fixed carbon	71.3%
Ash	9.4%
Sulphur	1.6%
B.t.u.	13,789

The term "smokeless coal" is a challenge to the combustion engineer. None of his art is needed to make anthracite and coke burn smokelessly, but as increasing amounts of volatile matter are associated in the fuel, more and more demands are made upon his skill in furnace design, in

*Analyses of Samples of Delivered Coals, by Ned. H. Snyder, Bureau of Mines Bulletin No. 230.

adaptation to service, and to care in operation to keep within absolute or even practical smokeless limits. Illustrations can be found of smokeless performance of every fuel, so that the statement can be made that "it can be done." That it is not done simply indicates that it is not wanted badly enough to pay the price. Most engineering is a compromise among conflicting requirements. Smokeless operation usually requires the cooperation of several interests, sometimes management of a high order, and often a degree of care and attention difficult to buy. Financial and operating limitations are many. All of these elements enter into the practicability of attaining smokeless operation, and obviously each case must be considered by itself.

THE SMOKE PROBLEM OF CITIES*

By Osborn Monnett
Consulting Engineer, Chicago

Increased interest in the matter of smoke abatement is being manifested in all parts of the country. While the necessity for something definite along this line becomes more and more apparent, it must be admitted that to date results in the main have been unsatisfactory.

In certain communities where, owing to concentration of industry or to physical surroundings, the smoke was so bad that something *had* to be done, marked results have been obtained, but taking the country as a whole the smoke nuisance is increasing alarmingly. Roughly, it may be said that the problem will increase in importance in direct proportion to the increase in the use of bituminous coal. Judging by the rate of increase in the past, an idea may be gained as to what is in store.

In hundreds of cities and fair sized towns no regulations whatever are in effect. Even in those cities where attempts are made to regulate installations the efforts are confined to the larger and more important plants and do not include small heating plants, which present a large part of the problem.

It is coming to such a pass that in common decency, to preserve cleanliness, health, vegetation, architecture and general civic beauty, something *must* be done.

This applies particularly to locations dependent mainly on bituminous coal, but even in our eastern cities, favored as they are with relatively cheap "smokeless" coal and anthracite, there is a noticeable increase in the dirt in the past few years.

In studying the nature of atmospheric pollution with special reference to visible smoke, as distinguished from ash particles, combustion dust, cinders, slag and similar matters of fuel origin, two rather sharply defined objects stand out:

1. Soot from high temperature fires.
2. Soot from low temperature fires.

Volatile matter subjected to a relatively high temperature is split

*Read by W. J. Wohlenberg, Associate Professor of Mechanical Engineering, Yale University.

up by the heat and carbon deposit, if any, appears in a finely divided state, rapidly diffusing into the atmosphere.

On the other hand, with low temperature combustion, as represented by fires in heating plants, especially in the small sizes, a thick heavy yellow smoke is evolved, rich in phenols, of an acid reaction, containing also occluded sulphur gases from the fuel.

The first class contributes largely to the haze which hangs over our cities, shutting off the ultra violet, life-giving rays of the sun, thus lowering the general tone of the community, while the second class acts more directly in causing damage to property and furnishings and carrying corrosive agents to the nose and throat, thereby predisposing to acute lung diseases.

The difference in ease of control of the two classes of smoke is very marked.

In the case of the large plant maintaining high temperature fires, conditions can be made favorable. Headroom, flame travel, draft, air admission, can all be provided for best results. The fuel is burned by a comparatively small number of skillfully supervised men, working with well planned furnace installations.

In the case of the small heating plant there is a large number of individuals without any supervision, shoveling coal into common fire pots without any refinement of design calculated to help the situation. It is not overstating the case to say that as far as the great mass of small household heating plants are concerned, there has been no advance in methods of burning coal in the last 100 years.

As a result of a consideration of the foregoing, it must be concluded that:

Hope of complete smoke abatement under present conditions rests mainly with the large plant; and the smoke problem of the future is the problem of the small heating plant.

While the great mass of the people know nothing of improved methods of firing, there are, as a matter of fact, standard methods that have been developed for handling soft coal which will bring about a great improvement.

It is possible to reduce visible smoke 75% with these methods without alteration of furnaces or change of fuel, other than burning

small sizes, which in itself is no hardship, inasmuch as they generally cost less money.

In small residential areas where intensive educational effort has been made smoke densities have been readily reduced 50 to 60 per cent.

St. Louis is the only city in the country where this particular phase of the problem is now being attacked on a large scale. A firing school is provided where hundreds of janitors and householders are receiving instruction by means of illustrated lectures and actual demonstrations on the floor.

It is possible to design small domestic heating equipment which will be practically smokeless. But such equipment could not be marketed without a demand. Surprising as it may seem, there has been no such demand up to the present. Various attempts to put on the market better apparatus for burning coal in this class have met with indifferent success. Provided fool-proof heaters were available, it would take a generation to get them universally adopted even for new installations.

The field for educational work and policing of districts is vast and offers the only immediate relief. The situation justifies the conclusion that in cities where raw bituminous coal must be the basis of fuel supply, smoke abatement is achieved only by the closest supervision of equipment, educational effort and the most unremitting vigilance in following up operation.

This in effect imposes a tax on communities based on geographical location, which tax very few of them have seen fit to pay. Thus progress has been slow and as long as the necessity of using raw fuel exists it will remain so.

The difficulties in the way of handling heating smoke have been outlined above to emphasize the need for some radical advance in this branch of fuel utilization.

The situation is a challenge to fuel engineers to concentrate on a field which has not had the benefit of research and development.

The obvious solution of this problem, to avoid at one sweep the human element with all the attendant difficulties and necessity for large replacement of existing equipment, is prepared fuel. This is a broad term which embraces many possibilities.

Whatever form it finally takes, a prepared fuel must stand on

its own legs and meet competition of raw fuels in the way of operating expense to the consumer. When this is brought about, we will be able to look forward with certainty to the time when smoke will be removed from the horizon as a civic problem.

DISCUSSION

ROBERT HASLAM.* As the speakers have shown you, we really have no problem in the industrial field; we can burn any sort of fuel we want, smokelessly. The big power plants, of course, with automatic stokers and proper handling, are doing it much better than the smaller ones, and are taking care of the situation quite finely. About the only cases I can think of, where there has been trouble in industrial plants, are some of the older power houses, particularly in New England, and I presume in other parts of the country, where they have the old style horizontal grate, with the grate top very close to the boiler. However, these plants are constantly becoming of less importance. So I really think when we speak about smokeless fuel, we can eliminate the industrial field.

When it comes to the domestic field, as Dr. Hood said, it is a question of supplying a coal that can't smoke. It isn't a question of trying to teach the householder how to use a smoky coal, because the average householder is not going to learn. They are too busy running the automobile or something else, therefore we have to furnish them with a smokeless coal.

I am not an expert, but in reading the literature, there is one thing I do notice. Out of a thousand investigations on low temperature carbonization, how many of them have been started with the idea of providing a smokeless fuel? As I look over the investigations, it seems to me that you can put most of them into certain classes. First, a certain percentage of them have a kind of fuel that they want to carbonize and want to try the effects of low temperature carbonization; then they hope to get out of that low temperature carbonization a material that they can sell at a possible profit. Many of our investigations will fall in this class.

The second kind of investigation has been carried out for the purpose of producing an enriching gas, either water gas or slightly carbureted water gas. The third line of investigation has been to work out methods of using waste fuel such as anthracite waste, and they have briquetted that fuel to make it a saleable product.

Then of course, not in this country, but in England, there has been another objective and that is to make oil for naval use or home consumption in times of trouble, and for that, of course, they turn to low temperature carbonization. So therefore we have four reasons for low

*Professor of Chemical Engineering, Massachusetts Institute of Technology.

temperature carbonization: to make certain coals profitable, to make an enriching gas, to utilize waste, and to make oil, but, how many investigations can you think of that started off with the idea of making smokeless fuel? I can think of only two; I don't know that there are not others, but that shows you that it is not common.

If we are going to make a smokeless fuel,—I see Dr. Lander down here and I want to say at the start that I hesitate to talk about domestic fuel in front of an Englishman, because our conditions differ so from those in England that almost everything you say with respect to England is wrong in the United States and vice versa.

In this country if we are going to talk about smokeless fuel, I think we must say first that gas is the chief and best. I don't think there is much argument against that. Second comes fuel oil. You may say we have very little fuel oil, but we will get it and we have to consider oil, whether we wish to or not.

Now, the third and most plentiful smokeless fuel is anthracite coal. The first two, gas and oil, will command a premium because you can make combustion automatic.

Everyone who knows anything of the heating problem in the home knows that it is a real effort. It is only reasonable that a fuel, the combustion of which can be made automatic, should command a higher price than one requiring hand firing. But as we mentioned before, anthracite is the most plentiful, and therefore any smokeless fuel which we make must compete with it. Let us see what the average householder who uses anthracite has found. First, he has found his supply very uncertain because of strikes. I think that this has hurt anthracite more than any other factor. Second, is the uncertainty of the price. I put price next, after the lack of supply. If we are going to make a smokeless fuel to compete with anthracite we ought at least to find a fuel that is competitive without these particular disadvantages. In very few cases have any great efforts been made to reduce the ash in our so-called smokeless cities. There has been some effort and I think there will be more and more.

Next come briquettes, and I dislike them because they make a fine ash. Therefore in handling, they are dirty. A clean fuel has got to be clean not only from the standpoint of what goes up the smokestack but also what goes into the ash-pit. It won't do to make a fuel that will be clean as far as the chimney is concerned but will be very dirty as far as the ash-can is concerned.

Also, I think if we are going to produce a smokeless fuel to compete with anthracite, we must increase the density. That is to say, we must have a density greater than thirty pounds per cubic foot to compete with the fifty to fifty-five pounds per cubic foot of anthracite. I have seen only one way to do that myself, never having done any investigating, and that is the compression of bituminous coal, while it is in the plastic state. It is possible that many of the bituminous men here

know more than I do about that and I hope they will discuss it. It seems to me that something will have to be done to carbonize under pressure in order for the coke to compare in density with anthracite.

I would like to call the attention of the gas people to the fact that if they can get one-half of the people who now use anthracite to use a coke or smokeless fuel, that they would get from that coke approximately all the gas that they now need. I don't believe that the gas industry will ever supply smokeless fuel that will thoroughly compete with anthracite until they really make a right-about-face and consider the smokeless fuel as the main product and gas as the by-product. Due to the historical situation of the gas industry, they look at the gas as the main product they are to sell and the coke to get rid of as best they can. I think it would be extremely profitable and desirable for a gas company to undertake making a smokeless fuel, strictly competitive with anthracite and then taking the gas that they get and either adapting it or modifying it for domestic use. It isn't unreasonable to expect it because the value of the coke in the consumer's cellar is very nearly equal to that of the gas delivered to the consumer. For example, it will cost about $9.00 a ton on the average for coke in the cellar of the consumer and the gas from this coke delivered to the same point might be $11.00. And so I believe the gas companies could make such a product at a profit if that were their main object, that is having it instead of coke as the by-product.

In connection with Dr. Porter's paper on the cost of low temperature carbonization equipment, I have very little to add. I was in correspondence a while ago with the firm that manufactures low temperature carbonization plants in Germany, or rather a man that worked for one of them, and asked his cost per ton of coal carbonized as compared with the cost of high temperature ovens. His figures,—I'll put it on that basis so as to make due allowance for the difference in cost between this country and Germany,—his cost was a little higher than Dr. Porter's. He said that the cost of low temperature carbonization plant would be a little under, but not very much under the cost of a high temperature plant. I should explain that he had built and operated a plant carbonizing only 70 tons a day, and it is quite possible that to compare the cost in that small plant with the cost of a larger plant would make some difference.

As to the emphasis on the value that is going to accrue from combining the gas and electric plant, I was very much interested in such a combination as Mr. Gill pointed out this morning and which was also pointed out this afternoon. The gas company can send to the electric company steam made from waste heat, and the electric company can turn back to the gas company by treating the coal, an enriching gas for water gas; in other words, there is a certain mutuality that ought to be very helpful.

O. P. HOOD. I have been very much disappointed this afternoon that a portion of the problem has not been attacked. I expected Mr. Porter to do it, because his title was "Economic Aspects of the Conversion of Coal into Smokeless Fuel." I believe that if we could get a true audit of the losses that we suffer from distilling soft coal, especially in the homes as has been brought out; if a true audit could be obtained of those losses in laundry and soap bills, in painting the outside and inside of our homes, in the deterioration of rugs and tapestries, in labor for daily cleaning, in health and accident costs; and that were used in the way suggested by Mr. Haslam, by the Gas Companies, in an educational way in the sale of coke and gas, that we would find out that it is really cheaper to live in a clean atmosphere and pay a premium for the coke.

CECIL H. LANDER. I thoroughly agree with the last speaker on that point. Of course it is an extremely difficult matter to bring such a consummation about without some kind of government aid or government subsidy or something of the kind.

There are just one or two other points to which I should like to refer. First of all, Mr. Haslam's reference to the work of the British Fuel Research Board—I can assure Mr. Haslam that our points of view are very much the same, although our conditions are quite different. I quite agree with him that the finest fuel is gas, inasmuch as it is the only fuel which can be absolutely purified. Three troubles may arise from burning solid fuel; one is caused by the tarry vapors, another by dust, and the third by acid impurities, and gas is the only fuel from which all three can be removed.

Then there is just one point in Mr. Haslam's remarks in which he seems to be under a misapprehension, and that is, with respect to the objects we are striving to attain in England. There is a widespread impression that the primary object of the research work in England on low temperature carbonization is to produce oil. This is not really the main object; oil can only be a by-product when you are dealing with a process that gives you at least three-fourths of the raw material as a solid product. Oil only came into the picture through the lesson learned in the Great War. Since that time both objectives have been followed simultaneously, but our main object still is to get a smokeless solid fuel and such oil as we can, not to get as much oil as we can and such smokeless fuel as is left. In my experience, you can not get the maximum oil production and at the same time a good hard smokeless fuel. I hope it will be done, but it has never been done yet.

With regard to the figures Mr. Porter gave, I was extraordinarily interested in those figures because I have, in London, various balance sheets made out, and of course Mr. Porter has never seen those figures, but I can assure him that they are practically identical with his. The difference between Professor Haslam and Mr. Pope lies in

the point of view. There are really two problems, one is to substitute a smokeless fuel for the high grade coal now burned raw, and for us this is probably the more important aspect in view of our consumption of some 40,000,000 tons of raw coal a year for domestic purposes.

The other problem of taking fines and the so-called waste products from a mine is quite different. It is concerned with a material that one naturally wants to work up and step up to a useful smokeless fuel, but it cannot affect our problem very much.

Mr. Pope's figures refer to the second problem, and appear only applicable if the carbonization is carried out on a limited scale. Mr. Porter deals with the larger and more general problem where you are dealing with both the large and small coal produced from the mines.

With regard to the location, Mr. Pope takes figures at the pit's mouth. Now, while that is absolutely the correct place to do the job with regard to waste materials and low grade materials, I am personally just as equally convinced that it is the wrong place to do the by and large job for the reason that the gas works is the only place where the full value can be obtained for the gas. The value of the gas for heating purposes at the pit head is far less than its value to a gas works, the prices obtainable being roughly in the ratio of one to five. As regards the coke I think it matters little where it is made. If made at the pit's mouth there will certainly be less *weight* of solid fuel to transport, but as the *volume* of the coke is roughly the same as that of the coal from which it is made, the freight charges will be much the same. Personally I believe, and hope, that the main work will be done at the gas works but that there will also be a number of plants working up the "waste" products at the collieries. There is room for both.

F. C. GREENE. I am inclined to side with Dr. Haslam a little bit in the larger industries of this country, with due respect to Dr. Lander. However, I've got my remarks put in reverse order. I should say I am inclined to side with Dr. Haslam on a number of points that he raises, and which Dr. Lander has settled for his country.

Now, when we come to ship low temperature char as we call it, we have got to take a coke rate in this country unless we can show that we have got, as Mr. Haslam said, a char of great density, and to get that density at low temperature is not an easy thing.

I don't know whether Dr. Lander's railway people charge anywhere from 10% to 30% or even more percent for handling a ton of coke a given distance than they do for a ton of coal, but that happens in this country, and it would certainly work a very great disadvantage to force the domestic consumer who uses that 40,000,000 tons to pay that. Our domestic consumption here, we will say—as a point of fact, we don't use grates,—is not very greatly in excess of what you have.

We will use about 10% of our 550,000,000 tons which would be about 55,000,000 tons, compared with your 40,000,000 tons, Dr. Lander.

Now, of course, we are using our coal not in fire places; we are using it in furnaces. I don't know if we keep on whether we will be using coal in furnaces at all, if the oil holds out a little longer. There are about 900,000 oil burners that have been put in in the last five or six years. I don't know how many have been taken out. (Laughter) So that as a matter of location of the plant, if it comes down to that, our people who have spent a good deal of money in this business are inclined to think that it should be at the mine.

Now, of course, if your low temperature process makes a great deal of gas, which seems anomalous to me, because low temperature does not make gas,—low temperature makes a charred fuel in which the gas is left, we will say, in potential form for the customer to have the advantage of, and you bring the volatile matter in the charred product to the point where he does not get smoke. You just give him all of the volatile he can take in his fuel without making smoke, and that is possibly 15% to 18%. So you don't need in this country at least to be bothered or worried or concerned about putting your carbonizing plant alongside the gas works.

Mr. Haslam was concerned about density. I think that is important; if you are going to give a customer a material that occupies twice the space in the cellar that the same fuel value of coal did, he is going to have a larger cellar or get his coal at different times. Of course many of them like to get their winter supply of coal early in the season so they can take advantage of the price, so the question is of importance, and I urge those who are interested in low temperature carbonization,—and there are many of you,—to get all the density in it you can, because it is important not only for shipment, but for your customer.

The question of ash which Mr. Haslam has raised, is of course much in the foreground. If you have say a 10% ash in the coal and you hand your customer something that has been carbonized at a rate of say ⅔ or maybe ⅘ of the original product, you will of course have an increase in ash. If it is 10% ash coal and you carbonize to ⅔, we will say, you have something in the neighborhood of 15% of ash, by weight in the charred product.

Now, here again enters a question of true low temperature carbonization, the upper limit of which is certainly somewhere in the neighborhood of 450°C. instead of 800°C.

The ash made will be fine, very flocculent; it will be a good deal of a nuisance. I have burned the low temperature charred material and you will find the ash to be very fluffy, a good deal like ash from consumed wood.

However, the man who is principally concerned in the amount of ash is not the man who pays for the fuel, but the man whose back is

strong, who hauls the ashes up the cellar steps, and he will find that he has a better volume of ash to lug out with true low temperature fuel than he had from the original coal. That I can verify,—I know it, I have lugged that out myself. However, when it comes up a matter of waste, perhaps I was in the same category with the man whose back was strong and whose head was weak,—he won't know it; the increase of weight isn't there, but if he sees ten barrels of ashes that he has to lug up the steps, instead of eight, he sees that; you must take that into account, that the increased weight or percentage of ash is not always a manifest disadvantage.

However, it is possible to reduce the percentage of ash. Most of us know that Mr. Walter Trent, who delivered an address to us yesterday, has been working very conscientiously for years to reduce the percentage of ash in coal, and we have investigated that from the commercial standpoint. It is unquestionably the right thing to do eventually,—but it puts me somewhat in mind of some years ago in my mining days, I was called upon to make a report at some mines that were part rock and part coal, and I noticed that their picking tables were idle, and I said to the manager, a fine sort of upstanding chap, "You are getting out quite a little rock here and your picking tables are idle; don't you have some complaint on that?" He said, "Well, we have no complaint." I said, "It's pretty dirty coal." I had shoveled some of it a few nights before, coming in on a train. And he said, "You know, rock weighs a good deal more than coal and we get paid by the ton, so that's what we give them." That may not be good morals or good business eventually, but it is what happened.

So there are people today using ten or twelve percent of ash and it may get up around fifteen percent. They are used to handling that; why should you bring down the ash to the original vegetable content of the coal?

I heard only the concluding part of Dr. Porter's paper. We, that is, my corporation, the Old Ben Corporation of Chicago, who have been developing a low temperature process (have developed a number of them as a matter of fact), but this one finally is developed, and they naturally kept very close costs as to what they did.

In the paper which I expect to deliver to you I believe it is tomorrow afternoon, I rather sidestep the question of costs. I just got the closing remarks of Dr. Porter and I do think that those of you who are working in low temperature work,—and there is plenty of room for all of you,—if all were put into operation we wouldn't have enough; those of you who are working on that would probably welcome some idea of what we had to go up against in a practical manner on costs.

Now, if we consider this from the standpoint in England that I understood Dr. Lander to speak of yesterday, where 18 shillings is the cost of the coal and we needn't expect to get more than 18 shillings

for the product, or roughly $4.50, how is that going to affect the cost of conversion?

I put down a few figures that are not actual figures,—I am not at liberty to do that. As I say, we got available costs; they vary a little bit, but suppose you note these down and then think over them; put down the coal which you could buy, that is the fine slack, screenings, which can be obtained for anything between $1.00 and $1.50, sometimes lower than a dollar, but we still take a price of $1.50 for a ton of screenings. We have a favorable freight rate, but we are going to do this at the mines and therefore we take the mine selling price of $1.50, which is a good maximum price. Now, a fixed charge; what enters into that of course is your investment. I heard the tail end about the cost of the carbonizing plant, that it would run a little under the cost of the coke ovens, we will say. I think that's about right; I would be inclined to put the cost of by-product plant somewhere around, say about $7.00 to $8.00 a ton a year; I think you will find such figures not very far off; $7.00 to $8.00 a ton a year, that is, investment for every ton a year would be $7.00 or $8.00.

Now, if you multiply that by the percentage of all your fixed charges, add them all up, take an average of twenty to twenty-two percent, add 22% on your fixed charges will give you somewhere around $1.50 a ton.

Now, there is your coal, your fixed charges and your labor. What is the price of labor? The usual coke oven work is one thing but when you get around the mines of the central competitive districts (and now in West Virginia as far as that goes), as explained to you a few days ago, you are paying a very high price for labor. In Illinois we pay for common labor, somewhere around a dollar an hour for a day of eight hours; along around seven dollars and seventy-five cents for eight hours. Well, of course we believe that is good business; if the laboring man gets good money he spends it and that's what makes prosperity, so you have to buck your high labor charge today against the operation of the mine, and I think a dollar will cover that,—you can check me up. You will find when you check it up that you have about four dollars. Does that come near your figures?

Now then, what are we going to get for our four dollars? I stand convicted of conservatism here, and that makes me feel a great deal better, but I do feel that you can beat that four dollars a little bit. Now, on the other side you put down your total sum under your realization of this four dollars. Suppose we take the by-products first. Somebody said that from the average good coal you can pay for the process by the selling price of the by-product. Well, maybe you can, but you have got to do quite a little bit of refining. But, suppose you sell your tar as a matter of fact to the Barrett people or to some other

people, you should get five or six cents a dry gallon for it; 5¢ would be probably a good fair average.

Now, how much tar do you make? If you make a lot of gas you haven't made a lot of tar, that's a cinch. But with your gas yield down low, you should at low temperature work get a very considerable yield of tar, twice as much and sometimes three times as much as you can get with a high temperature process. So if we assume there are twenty gallons of tar, which is twice as much as the high temperature plant,—twenty gallons of tar at 5¢, gives you a dollar of realization.

You have some ammonia as sulphate; you have your gas,—you must charge yourself with gas you used yourself. If it is an eight hundred or nine hundred B.t.u. gas it is certainly worth thirty cents in the holder. Charge yourself with it if you use it in your process. So that your ammonia that you would produce would amount to about ten pounds,—you would have ten pounds of ammonia as sulphate at 2¢, I think now; maybe a little lower than that,—if you get thirty cents out of your gas, let us call it fifty cents. It's the way you have to figure it, prices vary; you can only approximate them and be safe then. So you have a dollar, and for miscellaneous gas and ammonia, fifty cents. Now, if those figures are away off somewhere I would like to have somebody show me where. But I think that that is the way we ought to mop these things up, right at the time. I don't want to give out wrong information here,—I want to be conservative. So the by-product,—I don't think on the average coal that you would carbonize could be expected to give you more than $1.50, and $1.50 from $4.00 which you would realize, would leave $2.50.

Does anybody mean to tell me that at the mines, a solid product with the same B.t.u. in it, per pound and one that will ship long distances and burn slowly and non-clinkering is not worth over $2.50? How much is it worth? That seems to be the important question. Suppose we make our stuff in Southern Illinois on a large scale and ship it up to Chicago. We have $1.95 freight rate from our properties up to the Chicago district. If we sell it at $2.50, not making any money but sell it at $2.50 at the mines, which we don't propose to do,—take the $2.50 and add $2.00 in round figures for the freight, there is $4.50; in other words it is in Chicago at the market on board the car at $4.50. Now, how much over $4.50 are we justified in asking the dealers, who will in turn tack on something to the customer, to pay for the same? Upon the answer to that question, as I see it, depends the whole future of the low temperature carbonization process. And you are in competition with anthracite and also in competition with coke. Coke runs from $6.00 to $8.00 and up to $9.00, and at some times there come in those so-called smokeless coals from West Virginia and they will come in sometimes as low as,—I'll say $4.50 loaded in Chicago, something like that.

Well, now, somewhere in between that range of prices is what you are going to obtain for your low temperature char, unless of course you go to other means and utilize it for other purposes.

Now, that's the way I should like to see the balance sheet tackled to settle this question of the economics of low temperature carbonization. There is no question but what we could put up a thousand ton plant at Chicago, Peoria, Joliet, any place around where we want, and do a thousand tons of business, and get away with it and make big money, but that isn't the point. The point is to utilize the enormous amount of low value slack which exists in this country. The gas man can't use it, the power plant can't use it, and we have a growing amount of fine coal; very good fuel although in a very finely divided condition.

It seems to me that that is the way that we have got to attack this question of what the economics are of low temperaure carbonizaion, if we look at it properly, not what we can get for the carbon but what we can afford to charge the average consumer with the little furnace downstairs; he is the man who makes the smoke in our cities; the fellow who is responsible for the smoke in our cities is the domestic consumer.

I am going to leave that question with you. I would like to hear what you think about this right price on smokeless fuel.

A MEMBER. I think Dr. Porter has made a very good point in stressing the economics of this smokeless fuel. Regarding the question of a subsidy, as mentioned by Dr. Lander, the sentiment in this country is so strong against that thing that we can practically dismiss it as a possibility of supporting an industry.

A point that I want to stress particularly is this; in selecting the location of a plant, after all it is what the consumer of this fuel has to pay for it delivered to his own bin that is important and if the point of manufacture of this charred product is intermediate between the mines and the point of ultimate consumption, you have this difficulty to face, that there are two railroad hauls, and in delivering the product you have one relatively cheap rail haul to near the point of consumption and then a relatively high cost of trucking for the short distance to the local point of consumption.

It seems to me that the trend of making gas the by-product of the fuel is going to involve, as we progress in the distribution of gas to wider areas, the question of the distribution of this solid product. This brings in the involved question of how far you can afford to distribute by truck and how far you can afford to pay railroad freight and then truck.

I know that the extra loading which had to be carried by this char product by introducing the short railroad haul practically killed the

project in one instance. I think that is one point that Dr. Porter in his paper didn't stress as much as he might have.

After all we may work on these things as engineers, but when we cannot show satisfactory returns, the bankers will block our getting the money to put the thing through.

WARREN S. BLAUVELT.* There are two economic facts relative to smoke abatement which have not been stressed; the first is that the total annual damage caused by smoke and soot in almost every city of the United States exceeds the total cost of smoke elimination; the second is that you cannot induce Jim Smith to pay more for his fuel to avoid smoke emission from his premises if his neighbors continue to pollute the atmosphere. To succeed in smoke elimination, it is necessary, as Dr. Hood said, to reduce the cost of smokeless fuel to the individual consumer to about the cost of smoke producing fuels.

Now this can be done. We know enough about the technology of coal processing, gas making, gas transportation and distribution to warrant the statement that if there were no unnecessary financial burdens put upon gas manufacturing, transportation and distribution, the heating effects now obtained in built-up sections of cities by the consumption of bituminous coal delivered in retail lots, could be obtained at a lower total cost by burning gas. The politico-economic environment of the gas industry was established by politicians, not by economists nor by engineers. Everything that is done for the betterment of society is taxed. I believe it was Faraday who, when asked why the government should support some scientific investigation, replied, "Because, gentlemen, some day you can levy taxes on what may result therefrom." The burden of taxes on the manufactured gas industry, direct and indirect, is seldom less than twelve cents per thousand cubic feet sold, and in some cases more than twice that amount. Also, the gas industry is handicapped in many cases by inefficient or commercially obsolete equipment, on which the owners are permitted to earn 8% per annum on the present replacement cost.

The real problem in smoke elimination is to get technologists to use the scientific method in attacking the economic problem of the displacement of smoke producing fuels and appliances by smokeless fuels and furnaces with no increase in cost to consumers.

Unfortunately, when scientists and engineers leave their technical fields to deal with economic, social and political problems—the problems of human relations—they generally drop the scientific method and become the worst traditional possible—even worse than the lawyers. Some years ago I started to use the scientific method in studying the economics of the gas industry. The results of these studies were published in the following papers:

"Satisfactory Service at Low Rates," Gas Age, November 10, 1920.

*President, Vigo Mining Co., Terre Haute, Ind.

"Natural Law, Statute Law and Gas Service, Proceedings Indiana Gas Association, 1921," Gas Age, May 10, 1921.

"Why Gas Rarely Replaces Coal for House Heating," Coal Age, August 7, 1924.

These papers attempt to show the changes in the politico-economic environment of the gas industry, which if effected, would so reduce the cost of gas to consumers that it would be cheaper than coal; then within a very few years smoke pollution of the atmosphere would be eliminated without the necessity of employing the police power.

May I add that some twenty-five or thirty years ago President Nicholas Murray Butler in an address on Religious Education defined education as the adaptation of the individual to his environment, and the development of his power to alter that environment? It seems questionable, when one considers the politico-economic environment in which our useful industries are placed, whether the people responsible for the conduct of those industries have been educated through the second stage covered by President Butler's definition.

A MEMBER. In Dr. Hood's paper in the analysis of West Virginia coal and the Central Pennsylvania coal, I noticed that the B.t.u. value very rarely ran over 14,000. That seemed rather low to me, and I wondered whether they were derived by calculation or the calorimeter.

O. P. HOOD. I always hesitate to give analyses, because analyses can always be used in some illegitimate way. One has to know just what the analysis means, where it comes from, the conditions under which the sample was taken and how the analysis was made in order to truly interpret what the analysis means. I tried to give the picture for these analyses. I said that the Bureau of Mines has made about 1,000 analyses of delivered coal. Calorimetric determinations are made by the Standard method. This was of coal bought and delivered to the government under contract. The samples were taken at the point of delivery as the postoffice, or custom house. The results are published.

The average of these figures are what I gave you. That doesn't mean that if we had a true average analyses of say the Pocahontas field, that it would agree with this figure, because obviously in a true average we would have to have a weighted average, from the many mines in order to get a true picture for this year and then again next year it would be different. Please don't take those analyses too seriously.

HORACE C. PORTER. Mr. Blauvelt rather intimated that I should have taken up the economic side of the damages resulting from smoke, and why people will not pay high prices for smokeless fuel and do away with this horrible curse of smoke.

I tried to bring that out very briefly in refering to the psychology of the matter. The man in the street doesn't feel that he wants to put in an initial expense for intangible returns, and that is a difficult thing

to overcome, and I didn't think that the subject that was assigned to me justified going into that to great detail, but I alluded to it to that extent. Therefore, I think the great problem before us, is to produce smokeless fuel at a cost that will enable it to be sold at a price that will appeal to the masses, and the man that burns coal in a small boiler plant, for instance, and make it compete with low price bituminous fuel.

In answer to Mr. Greene's question as to what I said as to cost, I said very little, and I don't want to say much on that subject, because it is rather dangerous ground to tread on. He said a great deal more than I did on that subject. The great problem however, and the thing I wish to bring out is that the price must be lower on the fuels than they are at present if we are going to put this thing over, and be able to have a smokeless city.

A MEMBER. Mr. Hood started with the anthracite and said that as the volatile matter went up the smoke in it went up, but you pass a crest and go down the other side. That is probably well known to many people here, and when we get to the lignites we get to the smokeless coal. In the city of Adamton, in Alberta Province, you will find that probably everybody is burning lignite coal, and you could go out there, and I have done it at twenty and thirty degrees below zero and everybody was stirring up their fires in the morning, practically the worst time of day and you would see just the water vapors or condensed steam. That thing Mr. Hood knows better than I do, but I thought the outside public might get mixed up in that matter.

Dr. Haslam spoke about the pounds of fuel per cubic foot. I think he might go a little further and speak about the therms per cubic foot for greater practicability. The work of this conference as to smokeless fuel would be quite simple if only the transportation were feasible, but unfortunately the transportation of lignite to the great market is impossible. I regret for my own personal interest that this conference is confined to bituminous coal, but it is, and properly so.

FRANK M. GENTRY.* Dr. Porter in his very conservative paper has done a great service in pointing out the plain facts in the economics of smokeless fuel manufacture from which we are so liable to be misled by promotion propaganda such as is encountered in the initial stage of any new industry.

For some years I investigated the general question of low temperature carbonization in great detail and from the first it was apparent that there was a certain cost of conversion, arising from operating expense, overhead and thermal loss, which must be overbalanced by an enhanced value of the products sufficiently large to attract capital and compensate for the financial risk. To attempt to prepare an income account for a theoretical case is almost futile because so much depends on the

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market demand. Early in my work I decided upon certain market prices according to the grade of the products and compared the financial return to be expected from several score of low-temperature carbonization processes, basing the calculations upon installations of 1,000 tons capacity per 24 hours operating continuously and assuming that the amount of by-products would be insufficient to cause appreciable reduction in market prices.

In this connection I found that, with full knowledge of the large percentage of tar acids present, I could establish no sound basis at the present time for a price on the low temperature tar, after removal of the light oils, above that of its thermal value as a fuel oil and I assigned this value at 6¢ per gallon which I am gratified to see agrees exactly with the finding of Dr. Porter. Of course development of new uses for the tar may make it necessary to revise this conclusion in the future. The market price of ammonium sulphate, if it is recovered, can pretty well be placed at $2.50 per 100 lbs. The market value of the gas is a more serious matter, for unlike tar it cannot be put in tank cars and shipped and it may be difficult or even impossible economically to build pipe-lines to the market. A case is known where the same 570 B.t.u. coke oven gas was sold to the town supply at 34¢, the surplus to steel furnaces at 17¢ and the remainder for power purposes at 6¢ per 1,000 cu. ft. This illustrates the difficulty of setting a price on the gas in advance of contract agreements. Another case is known where 900 B.t.u. gas is burned under boilers in enormous quantities within 15 miles of one of our largest cities because of difficulties of transportation. In another part of the country, not 2 miles from a large city, vast quantities of natural gas are wasted into the air for lack of a market. Considering that the average cost of manufacturing 550 B.t.u. city gas, as reported by ten Massachusetts Communities, was about 30¢ per 1,000 cu. ft., Dr. Porter's figure of about 36¢ per 1,000 cu. ft. for 800 B.t.u. gas is certainly not exaggerated. In my calculations I assigned a straight B.t.u. value to the gas based upon the average cost reported by these communities, fully realizing that higher calorific gases were more valuable on account of the heat concentration than that determined by linear proportion. This method gave about 42¢ per 1,000 cu. ft. per 800 B.t.u. gas. The light oil suitable for motor spirit is certainly undervalued at 15¢ a gallon. Regarding the value of the semi-coke, I am inclined to agree with Dr. Porter in assigning it the same value per pound as the raw coal in the case of its use as a boiler fuel where its higher ash content is more than compensated by its increased efficiency, but in the case of its use as a domestic fuel, I am inclined to believe that its evaluation must depend to a large extent on the product. Thus some of the soft fragile lumps of semi-coke are certainly worth no more or even less than the raw coal, while on the other hand some of the highly compressed cakes or briquets will cer-

tainly compete with anthracite and bring a price only sufficiently below hard coal to attract buyers.

From the foregoing, it is indeed apparent that no generalizations can be drawn as to what financial return may be expected from the low temperature carbonization of coal. It depends entirely too much on the particular process, the market, etc. In the majority of the many processes for the production of smokeless fuel that I have investigated, I agree with Porter that the financial return is too meagre to attract capital, but at the same time I have examined some processes, mostly those yielding a product comparable to anthracite, which appear to be attractive as commercial enterprises even with present markets.

If I understood correctly, Dr. Porter assigned a loss in heat value of 25% of the raw coal. This seems to me excessive, for I believe it has been shown that the theoretical heat necessary to carbonize the coal is less than 4% and from the heat balance that I have constructed from many reported tests, the loss in carbonization, radiation and sensible heat is about 8% or 10% at the most, certainly not more than 15% in any case and a certain amount of this is recoverable by a rational extraction of sensible heat.

I would like to take this opportunity to make a plea for more rationality in reporting test results. The British measure their tar in Imperial gallons, the Americans in U. S. gallons. The British results are rewritten in American journals without translating the units, much to the confusion of the reader. Some experimenters even report their tar yield before dehydration, and one usually has to guess from the size of the figure whether it is the scrubbed or unscrubbed thermal value of the gas that is given. And worse yet, yields and analyses of the gas, the tar, etc. are ofen given without an analysis of the raw coal! One is apparently supposed to judge the efficiency of a process without knowing the input. All of this confusion could be avoided by more care in reporting and interpreting results. It might be mentioned in this connection that there are weight balances and thermal balances computed from published accounts of a number of authorities that were wholly an impossibility from the established laws of mass and energy.

A. BEMENT.* The problem of smoke in cities using bituminous coal continues to be a serious nuisance and an economic waste in heating service, such as the apartment house and residence, notwithstanding that most makers of power furnaces have solved the problem with the equipment they produce. In this respect the manufacturers of low pressure heating boilers have shown comparatively little development away from the old flat grate which serves the purpose with anthracite coal. In my opinion, the makers of such equipment have a real opportunity not only to render the public an important service, but to develop a more satisfactory and profitable business for themselves.

*Consulting Engineer, Saline County Coal Corporation, Chicago, Ill. (Submitted in writing after close of meeting.)

It is the low pressure heating service in apartment houses especially that I propose to discuss. Not only smokeless and efficient combustion is essential but labor cost is of very great importance. Cost of janitor service is influenced by the attention that the furnace requires, especially in those cases where a man cares for a number of buildings. Therefore, the length of time a boiler fire may function before requiring attention has a definite economic value.

The down draft furnace is a device which when properly designed and operated gives high efficiency, complete combustion, and a long firing period. Several makers of heating boilers have attempted to produce a boiler of this kind. These attempts however, in a large measure, have failed to meet requirements.

Figure 1 is a sectional view of this furnace, as applied to a steel boiler. The grate C is composed of tubes through which water circulates as part of the boiler. The arrangement of these tubes is also shown by H in Figure 2. The fire rests on these water tubes. The fresh coal is applied to the top of the fire by way of the feeder door B. Air for combustion enters through draft gate mounted on door B. Hot coals that may drop between the tubes of the water grate fall on a lower cast-iron grate E, where they may be burned. F is the usual ash pit below.

The scheme of combustion is the same as that of the underfed stoker, with which the coal is forced under the fire. The volatile gases

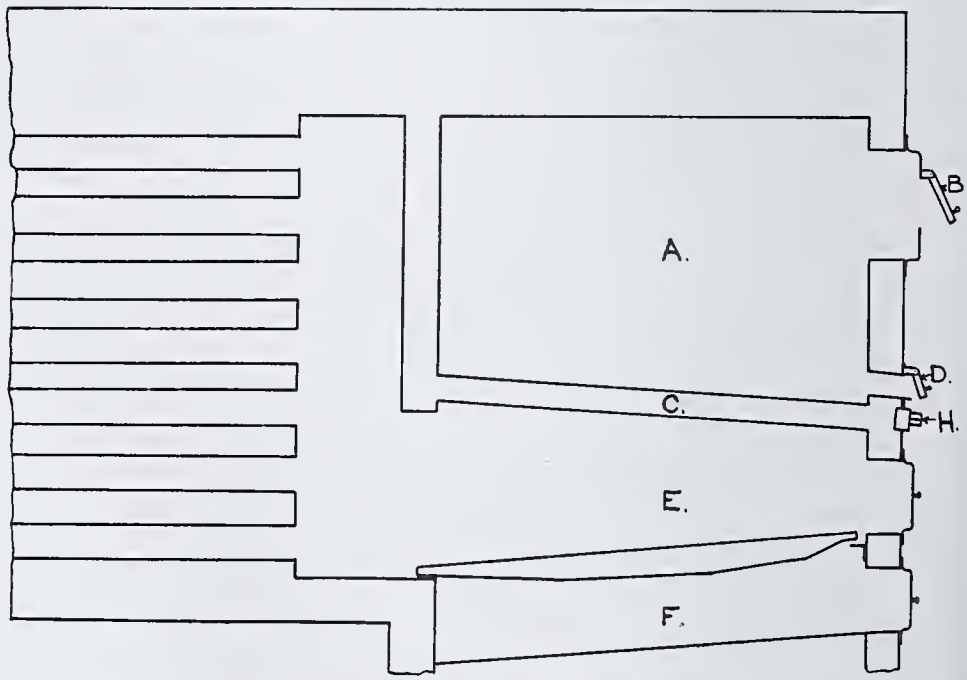


Fig. 1. Section of Down Draft Furnace

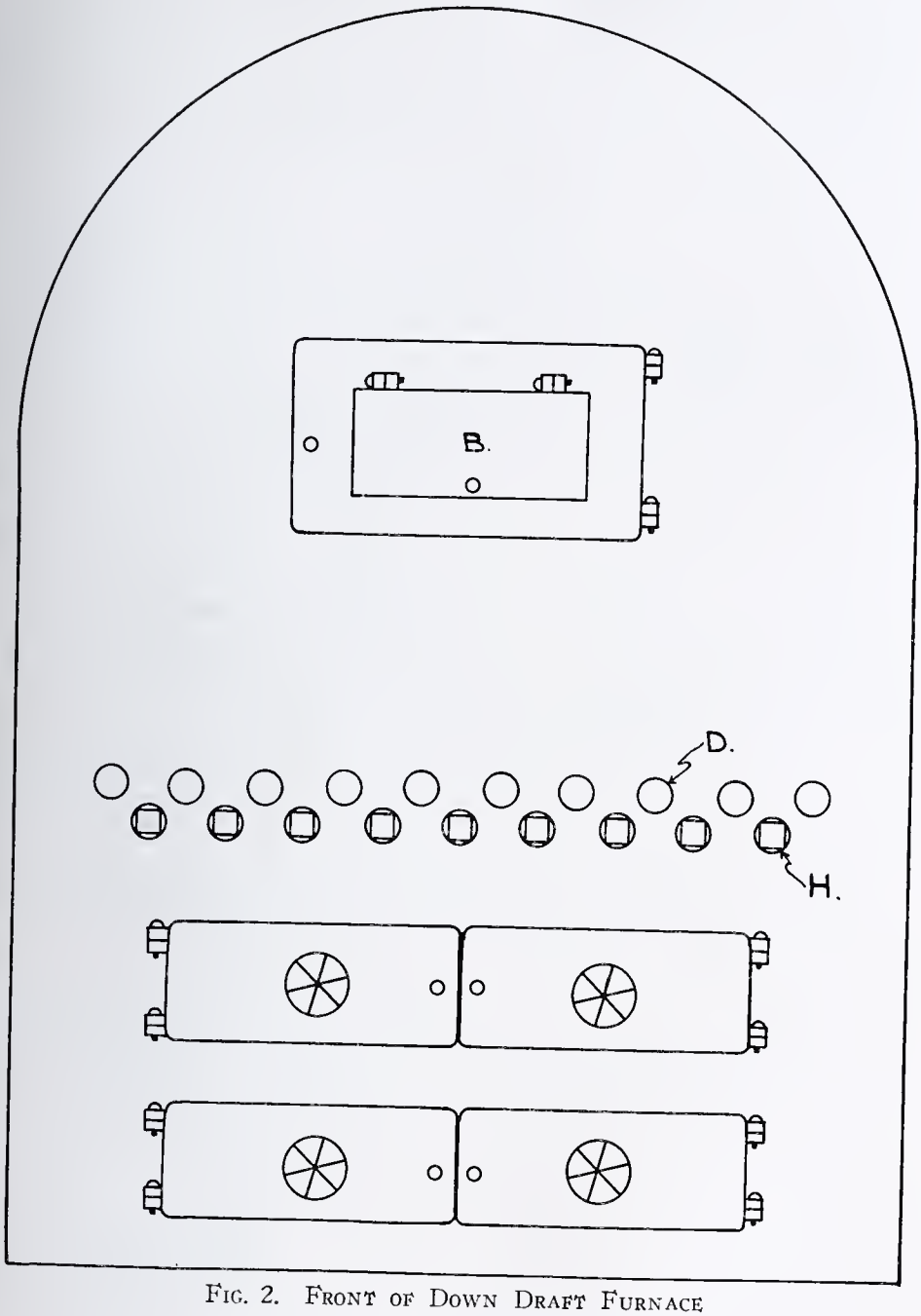


FIG. 2. FRONT OF DOWN DRAFT FURNACE

ascending through the hot fuel, together with the forced air supply, insures complete combustion, because the bases and air are forced into intimate contact while passing through the hot fire, producing immediate combustion. The action of combustion is the same with the down draft fire except that the process is reversed, the coal being placed on top of the fire and burning downward. Disposal of resulting ash and clinker, however, is entirely different. With the underfed fire, the ash emerges, is forced out, from the fire in the form of clinkers so that they do not clog the fire or interfere with combustion. With the down draft fire, however, as the coal is burned the ash moves downward into the lower part of the fire, where unless removed, it remains to be melted into clinker obstructing combustion. Failure to provide means for ash removal from the fire is one of the two special reasons for the failure of the down draft furnace as applied to heating service.

The Hawley furnace at one time extensively employed for power boilers, is the original down draft device, the same principle as shown by Figure 1, except the fuel chamber A was not so high, and that the fuel charging, or fire door B, was set as low as the location of the water tube bars would allow. These boilers being used for power were worked at a high capacity as compared with the low capacity required in heating service. Screenings which were usually used as fuel matted together making a dense fuel bed which required that it be broken. This was done by running a slice bar under the fire between each water bar, then by prying up the bar the fire bed was broken; at the same time the bar dislodged the accumulated ash which dropped down to the lower grate. In this way, the fire was always kept clean and there was no clinker formation. With the firing door set so low it would not have been possible to have carried a thick fire because the coal would have rolled out of the door. With the Hawley furnace, owing to accessibility, due to the low firing door, the fire could be kept in a clean condition all the time.

The attainment of a long firing period in heating service requires the use of large sized coal, because it will not mat together and obstruct the draft, and large coal requires a thick fuel bed, not only to prevent excess air through the fire, but to provide sufficient fuel supply to insure that it last for a considerable time, and so give the long firing period desired. When the down draft principle was applied to heating service, the fuel door was necessarily set so high that the slice bar could not be used as it had been with the Hawley furnace to dislodge the ash, so it remained to be fused into clinker, where it remained on the water bars to obstruct combustion until removed by digging down through the fire from the top by way of the firing door. This process is laborious, consequently not popular with janitors, and results in so spoiling the fuel bed that green coal gets down on the water bars, also falls to the lower grate producing serious smoke.

In certain instances purchasers of the Kewanee type of down draft boiler have provided means for poking the fire in the same manner as done with the Hawley furnace, as shown by H in Figure 2 and at D in Figure 1. It consists in cutting through the water leg and expanding nipples in place which affords a passage for a slice bar between and just above each bar. The relation is shown by D and H of Figure 2. These openings when not in use being closed by suitable means. This expedient, of course, gives excellent results, but is not a feature of boilers offered by the maker. Some manufacturers of cast-iron boilers provide poking holes in this location, but they generally do not extend for the full width of the fire; for this reason, are only partially effective, but most of the various boilers are not provided with any other means of ash removal than to dig into the fire from the top to get the ash after it has been melted into clinker, and which must be removed by way of the door of the fuel chamber. To remove ash in such cases a tool has

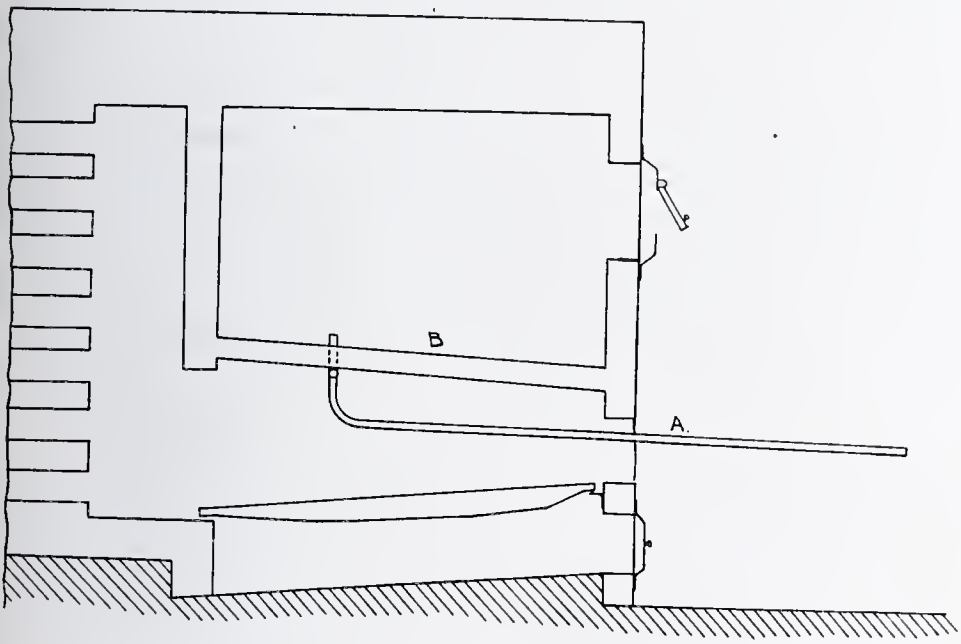


FIG. 3. SHOWING USE OF ASH HOOK

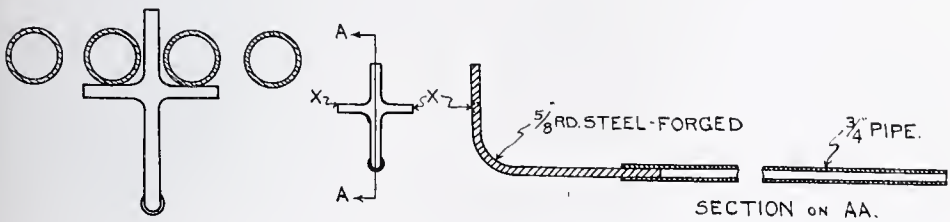


FIG. 4. SHOWING STYLE OF ASH HOOK

been devised, which has come to be known as an ash hook, shown by Figures 3 and 4. This tool is inserted through the door of the space below the water grate, and the ash is scraped or hooked from the bottom of the fire from below, the end of the hook projecting a sufficient distance above the tube of the grate to effect that result without unduly disturbing the fire. To facilitate easy manipulation guides are provided as shown by Figure 4 which not only facilitate the handling of the hook, but control the extension above the water grate tubes. This tool has proven a most useful device and is being quite rapidly adopted for boilers now in service.

The other principal respect wherein the down draft boiler as now made has failed to meet requirements, is with respect to the coal chamber; in other words, the space above the water fire bars. In some designs, one in particular now abandoned for that reason, the coal space was so shallow that it was not possible to get fuel bed thick enough to prevent such serious excess of air that the efficiency was so low that boiler ratings could not be attained with the maximum quantity of coal which could be burned. One of the causes of a shallow coal chamber has been the mistake in giving too much space to the chamber between the upper and lower grate, and to the ash pit, especially the former. Then to keep height of boiler within basement limits, height of coal chamber has been sacrificed. The lower grate should play but a very minor part in the performance; if the furnace can be, and is, handled properly, all that it should be called upon to do is to burn a few pieces of hot coke that may drop down from above and catch the ashes from the fire, which may mostly be removed directly from this grate without going to the ash pit. This implies the use of a plain stationary grate bar; a shaking grate for the location is not only unnecessary but objectionable.

In a certain case, a very large down draft boiler provided with a comparatively high coal chamber, but with no means of ash removal, had given serious and continuing trouble, due to clinker formation, until the ash hook before mentioned has been adopted. With its use clinker trouble ceased, and it was possible to charge this boiler with 1500 pounds of coal at one time, entirely filling the coal chamber which was sufficient for twenty-four hours; in other words, gave a twenty-four hour firing period in coldest weather. A rather exceptional case, no doubt, yet indicating possibilities.

To summarize—For smokeless, efficient results at moderate labor cost, I have concluded that the down draft principle, with the use of suitably large sized coal, and capacity to charge a sufficient quantity, together with provision for ash removal and adequate draft control, will give the best results possible in burning coal in heating service, and at the same time make the janitor's work easier and more pleasant, which is of especial importance, as it is not feasible to expect him to improve his practice, unless by so doing he lightens his task.

FUNDAMENTAL STUDIES ON COAL AS RELATED TO CARBONIZATION PROBLEMS

By S. W. Parr
Professor of Applied Chemistry, University of Illinois

A prominent writer on fuel topics has recently said, "There is no more pertinent question before the coal man today than this one of low temperature distillation." A unique feature of this conference aside from the very great importance of the topics themselves is the fact that the first serious investigation of fuels in America was made in the year 1826. It would seem eminently proper, therefore, that a brief historical review be made of the first 100 years of study connected with this all-important material.

The salient feature of these earlier studies on coal is the fact that they were of a simple character and were concerned almost entirely with questions of relative values. They were the direct reflection of the industrial needs of the time. The power engineer wanted to know the input and output of his plant. His needs were few and simple and could be stated in terms of ash, water, combustible and heat units. The gas engineer was equally modest and included perhaps one or two additional factors, such as the number of cubic feet of gas per pound of coal, and the percentage yield of the coke produced.

Now what is the forecast for the new one hundred years upon which we are just entering? First and foremost we seem suddenly to have discovered that the old methods of proximate and ultimate analysis, while they might serve a few specific industrial needs in the past, were utterly lacking as a source of information to any one seeking a deeper insight into the possibilities of this very complex material. As a result there has already been opened up a new era in coal investigation which will certainly characterize the transition which this conference has the peculiar honor of emphasizing, an era in which we shall be primarily interested in the fundamental topics already coming into prominence in connection with studies on coal, such as composition, reactivity, solvent analysis, thermal decomposition, structural modification and synthetic expansion, into fields that are fascinating in their possibilities and doubtless as bewildering as they are inviting. All of

which emphasizes again the very evident fact that progress in fuel research of the future must be based on very different factors from those which were quite sufficient in the preliminary stages, and for these fundamental studies the future holds out great encouragement by reason of the many new tools which present day developments in all of the physical sciences have sharpened and put in order ready for our use.

Having already ventured upon a historical reference antedating the present by an even 100 years, I would like for a moment to go back to an event still more remote, not only because of its historical interest but also because, at the very outset, I would like to bring into the picture the vast mid-continental area of bituminous coal commonly referred to as the Illinois Field. This area with its slight extension into Indiana and western Kentucky has an estimated tonnage reserve equal to the *combined* reserves of Pennsylvania and West Virginia *twice over*. When reckoned in square miles it is equal to the combined coal areas of all Europe including the English, Scottish and Welsh fields added together and multiplied by 3.

Coal was first discovered on this continent in Illinois, and I trust I may be pardoned for the personal reference when I say that by birth and pioneer inheritance I am from Illinois and that within the range of

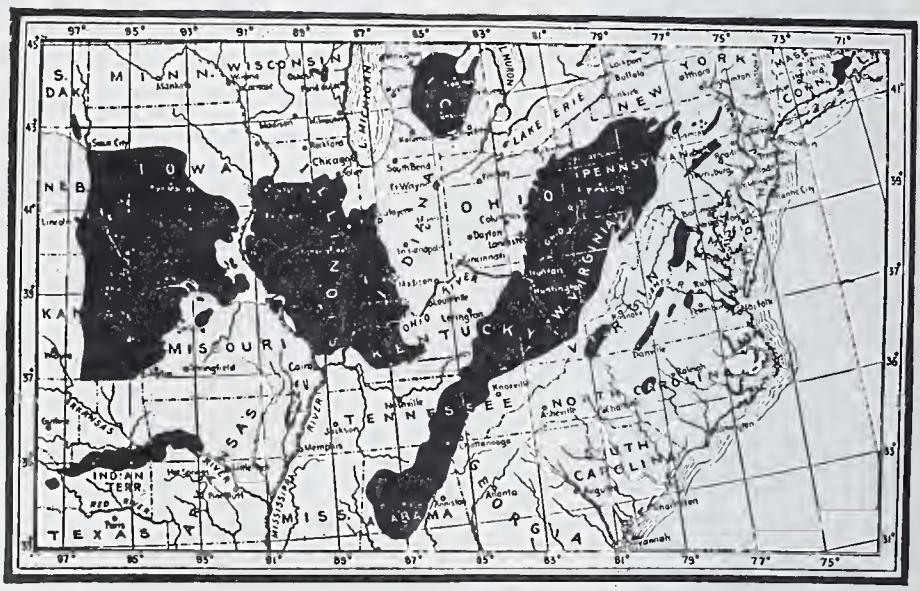


Fig. 1. Coal Fields of the United States East of the 98th Meridian

my boyhood environment was located the spot where the discovery of coal in America was first made. This was at a point approximately opposite Starved Rock on the north side of the Illinois River not far from Fort Crevecoeur. The exact location is very clearly marked both by geological outcropping as well as by the map which accompanies the journal of the discoverer—Father Hennepin. The date also of this discovery is well authenticated and it may be noted in passing that this present Conference on Bituminous Coal only deviates by a few months from the 250th anniversary of this discovery of coal in America.

In view of this early knowledge of the presence of "cole" as discovered by Father Hennepin, it is of interest to note further that the actual mining of coal in Illinois occurred substantially contemporaneous with the earliest production of anthracite in Pennsylvania and of bituminous coal in Virginia, the first recorded account making note of the fact that a shipment of coal was made from Jackson County, Illinois, on the Big Muddy, a flat boat being loaded at that point in 1810 and sent down the river to New Orleans.*

Reference has already been made to the fact that investigational work on fuels in America was begun just 100 years ago. I can not let the occasion pass without brief reference to some of the initial activities as well as some other events along the route covered by the first century, not only because of their historical significance but also because they illustrate in a striking manner the main objectives which characterized the studies of that period, already referred to as empirical and directed primarily toward meeting the immediate industrial needs of the time.

The first published account of investigational work on American fuels was embodied in a paper read before the American Philosophical Society of Philadelphia on April 7, 1826, and printed by the society later in the year. The current year 1926 therefore marks the 100th anniversary of the first published account of fuel research in this country.

The author of the paper thus referred to was Mr. Marcus Bull and he seemed to be animated by two principal objectives: first, that the newly proposed calorimeter by Count Rumford was not effective. You will recall that Rumford burnt shavings in a chafing dish and con-

* Coal Studies at the University of Illinois, by S. W. Parr.—The Technograph Vol. 23, p. 121 (1921).

ducted the hot gases through tubes immersed in a known weight of water. He was obliged to make his own thermometers as well as all of the metal parts of his outfit except the chafing dish—and though his apparatus was crude in many ways he was the first to propose the burning of a known weight of fuel and transmission of the heat to a known amount of water, as a means for arriving at fuel values in terms that could be expressed in some kind of a standard unit.

In the second place Mr. Bull was impressed with the superiority of coal over wood as a fuel for all purposes. Not content with Rumford's method, he directed his efforts towards the development of an

Fig. 2. Calorimeter Room

outfit that would yield values directly in terms that everyone could understand. He designed for this purpose what was in reality a calorimeter even though it was a small insulated room, approximately 8x8x8 feet in size, in which a given weight of fuel was burned in such a manner as to maintain a fixed temperature for a measured length of time. A series of ratios was thus obtained as between a chosen standard and a fuel under observation. The standard fuel thus selected by Mr. Bull, chosen doubtless because of its familiarity to all fuel users, was shellbark hickory wood, and it is of especial interest to note that in those early days there was no such thing as a "smoke nuisance" since the use of bituminous coals for all purposes was less than 2% of the total fuel used.

This initial investigation by Mr. Bull was directed specifically to the determination of relative efficiencies, and we should recall again the statement made at the outset that aside from its historical interest his work is a good illustration of the fact that the earlier problems were of an elementary type. But even so, they met the needs of the time.

One other reference should be made in further substantiation of the fact that the earlier studies were of a relatively simple order. A very

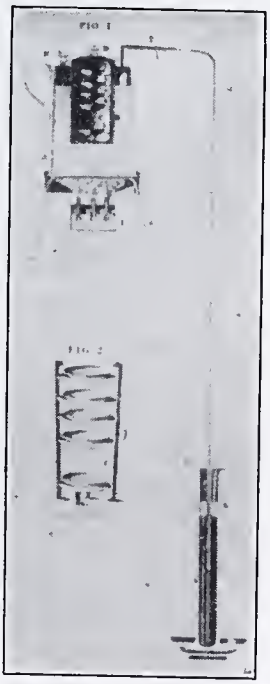


FIG. 3

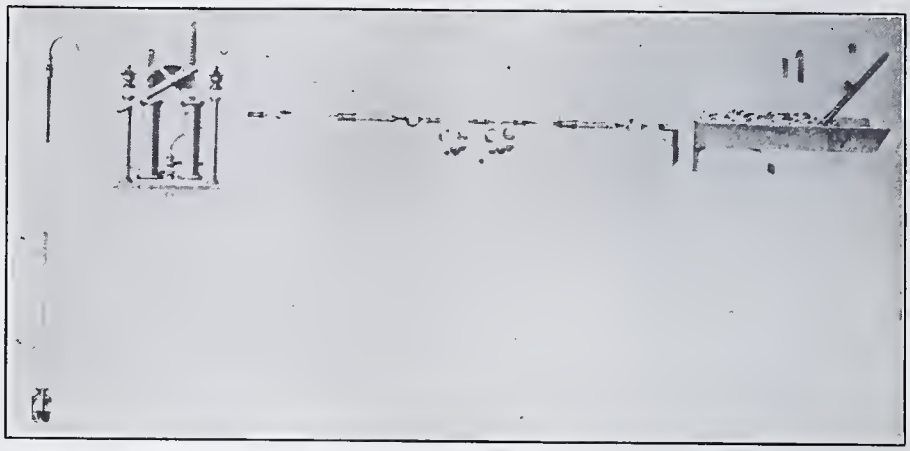


FIG. 4

remarkable but very little known investigation was published in 1844 by Walter R. Johnson entitled "A Report to the Navy Department of the United States on American Coals Applicable to Steam Navigation, and to Other Purposes." This report constituted a book of 606 pages and gave in detail the data connected with complete evaporative tests on forty-three samples, three of which were shipments from England, Scotland and Nova Scotia, and one was American wood.

"In setting forth the results, 200 tables were required, which for the most part were double-page in size. In one of these tables, Johnson, following a propensity which characterizes many of these tables, put his results in the form of a ratio and in this particular table the coals tested are arranged in the order of the ratios of the fixed carbon to the volatile matter, and this ratio is shown to have a constant relation to the evaporative power of the fuels tested. Here, it will at once be seen, originated the term 'Fuel-Ratio,' which in a general way serves as an index of coal values.

"One cannot go through the pages of this report without marveling at the indefatigable energy that must have characterized the author, the skill with which he developed a technic along lines having no established precedents to follow, and the wisdom with which he arranged and interpreted his results."*

One other reference only need be cited. In connection with the St. Louis Exposition of 1904 there was inaugurated by the United States Government an elaborate series of experiments which involved an

* A Pioneer Investigator. By S. W. Parr. Ind. Eng. Chem. 18-94 (1926).

extended series of evaporative tests and resulted in an imposing array of analytical value, both proximate and ultimate, including also calorific values, both calculated and determined—still having as the dominant idea throughout the determination of *relative fuel values.*

But the fuel venture of St. Louis in 1904 served one good purpose at least. It developed an appreciation of the need for more profound studies in that line, and so out of it all has grown the research laboratory of the Bureau of Mines of Pittsburgh, which has been pioneering along studies of a more complex and fundamental type, and along lines which already are represented by a fair array of investigators elsewhere.

And so we have reviewed hurriedly and in barest outline our first cycle of 100 years. It is evident on all sides, and this conference is a decided confirmation of the fact, that there are now many investigators delving after other problems than the determination of relative efficiencies in the production of power or heat.

Not a few of these investigators are centering their efforts on problems relating to the processing of coal, which has for its fundamental idea the segregating of values hidden in the complex chemical structure of the coal in such a manner as shall yield specific values or conserve values now lost in the present crude methods of generating heat, especially in household appliances; and above all producing a fuel for household use that shall be smokeless in combustion, thus eliminating the greatest contribution to the "smoke nuisance" that now exists. This objective, with its freedom from dirt and grime and its potential contribution to health, must unquestionably characterize the second century of investigational work on fuels, upon which we are now entering.

If we may turn now for a moment to the coals of the Illinois field, they are given the rank of true bituminous coals, but they are of such a different character from those of the Appalachian region as to be ordinarily designated as of the non-coking type. This is hardly a fair designation, for studies carried on using solvents for extracting the coking or bonding principle show that constituent to be present in very considerable amount.

It is true that if we set a ratio between oxygen and hydrogen for coking coals of 1 or 1½, then Illinois coals with a ratio of 2 to 2½ would fall outside of the coking range. A study of the constitution of these coals, however, seems to indicate that it is not so much a matter of oxygen and hydrogen or quantity of the coking constituent as it is its character—the readiness with which it may change altogether as a result of reactions from without or rearrangement within its own structure whereby its properties become altogether different.

There must be observed at every stage the conditions as to time and temperature which shall conserve in the highest degree the essential character of the coking or bonding substance of the coal. The simple formulation of the conditions emphasizes their paradoxical character. We are to carry quickly into the center of a mass of non-conducting material a certain range of temperature by means of a relatively low heat head at the exterior.

The studies on low temperature carbonization at the University of Illinois were begun early in the year 1902. This suggests the fact that like all other attempts of the period there was neither "rime nor reason" in the methods followed, and from the outset there was ample evidence that progress must wait on information

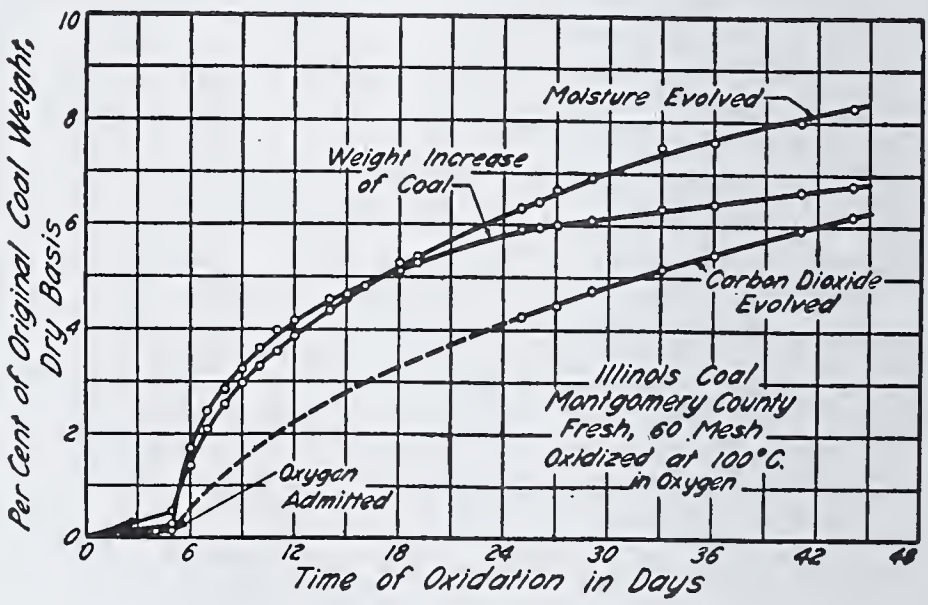


FIG. 5

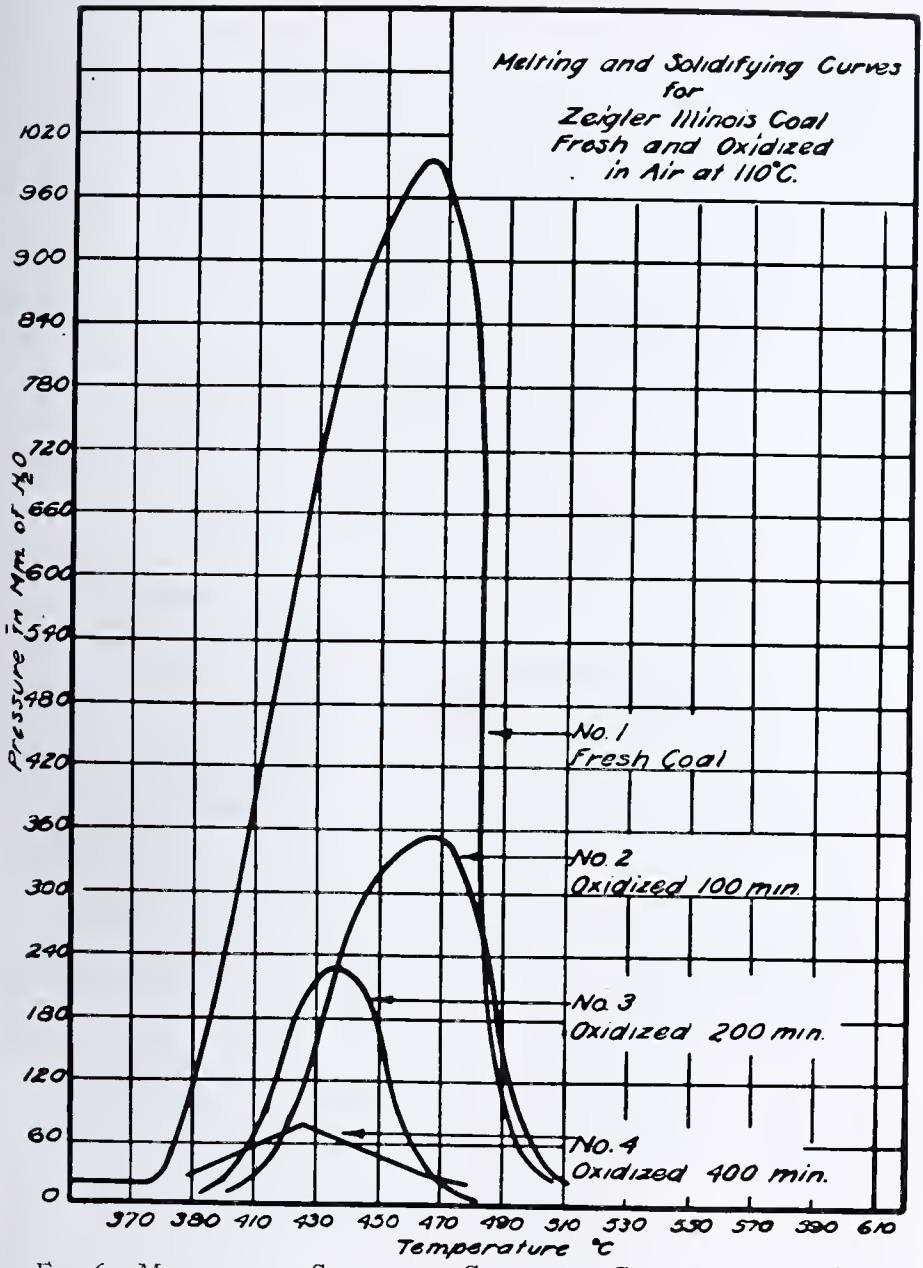


FIG. 6. MELTING AND SOLIDIFYING CURVES FOR ZEIGLER ILLINOIS COAL

of a fundamental sort which in a general way would be covered by the question, "What is the constitution of coal?"

It will be impossible in this brief reference to go into any of the details which have characterized this long-time study. One or two illustrations only can be given: It is well known, for example, that freshly mined coal has a great avidity for oxygen. What takes place in this absorption process is of fundamental importance so far as the coking of the coal is concerned. The fact is very clearly developed that this is not merely an absorption of oxygen, but a reaction *with* oxygen which changes radically the character of the coal constituents. This change is most strikingly shown by the fact that as the taking on of oxygen progresses, the bonding within the coal grows weaker and weaker until it is lost entirely.

Another evidence of change in the character of the constituents in coals of this type is shown in the change which accompanies the melting or pasty stage of the coal upon the application of heat.

Fig. 7. Coal Conditioning Drum

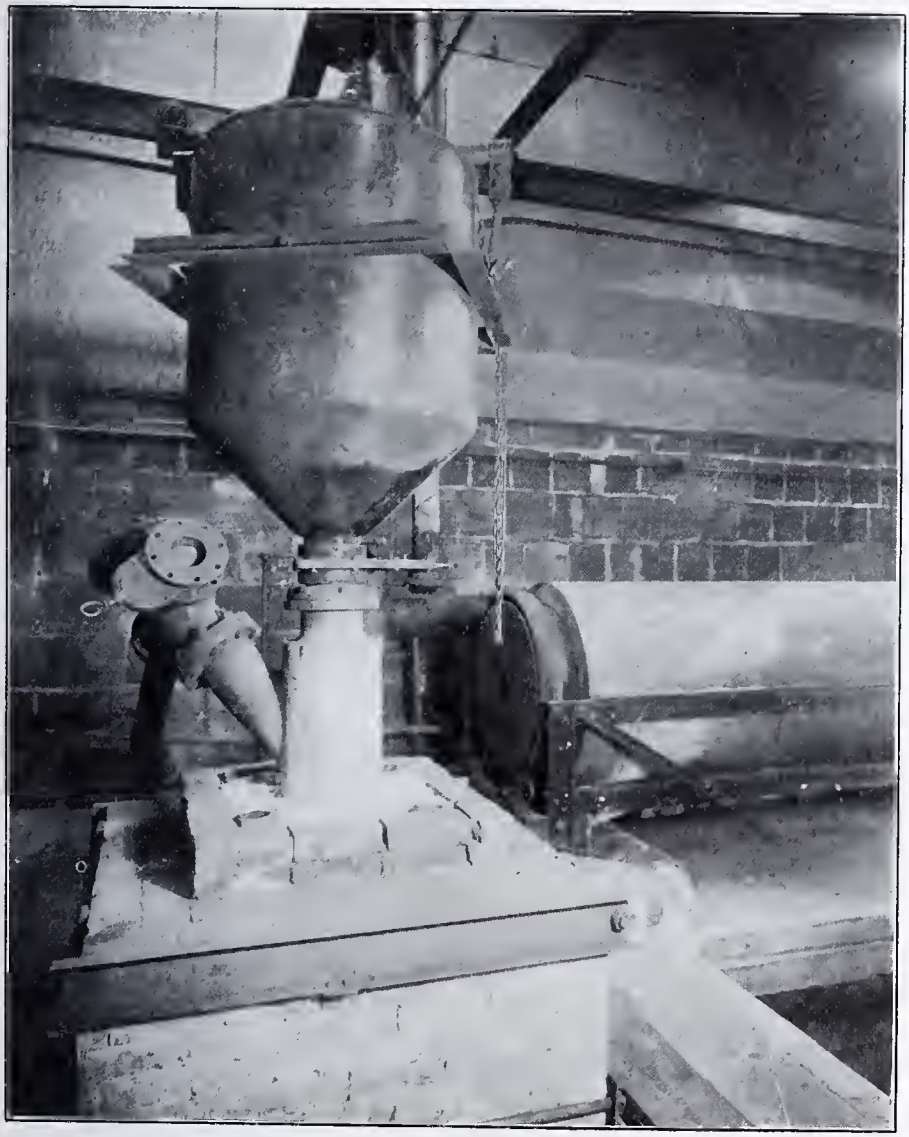


Fig. 8

Here again the type or extent of pastiness grows less and less as the oxygen reactions continue, until it is lost altogether. A conservation of the melting property therefore is absolutely essential if we are to secure a homogeneous, dense and strong texture at the end of the decomposition process. When obtained, there is positive evidence in the resulting product that deleterious and destructive reactions have been avoided and that a condition of pastiness or semi-fluidity has at one time existed throughout the mass.

The problem stated in general terms therefore is this: While avoiding deleterious or destructive reactions how can a thermal

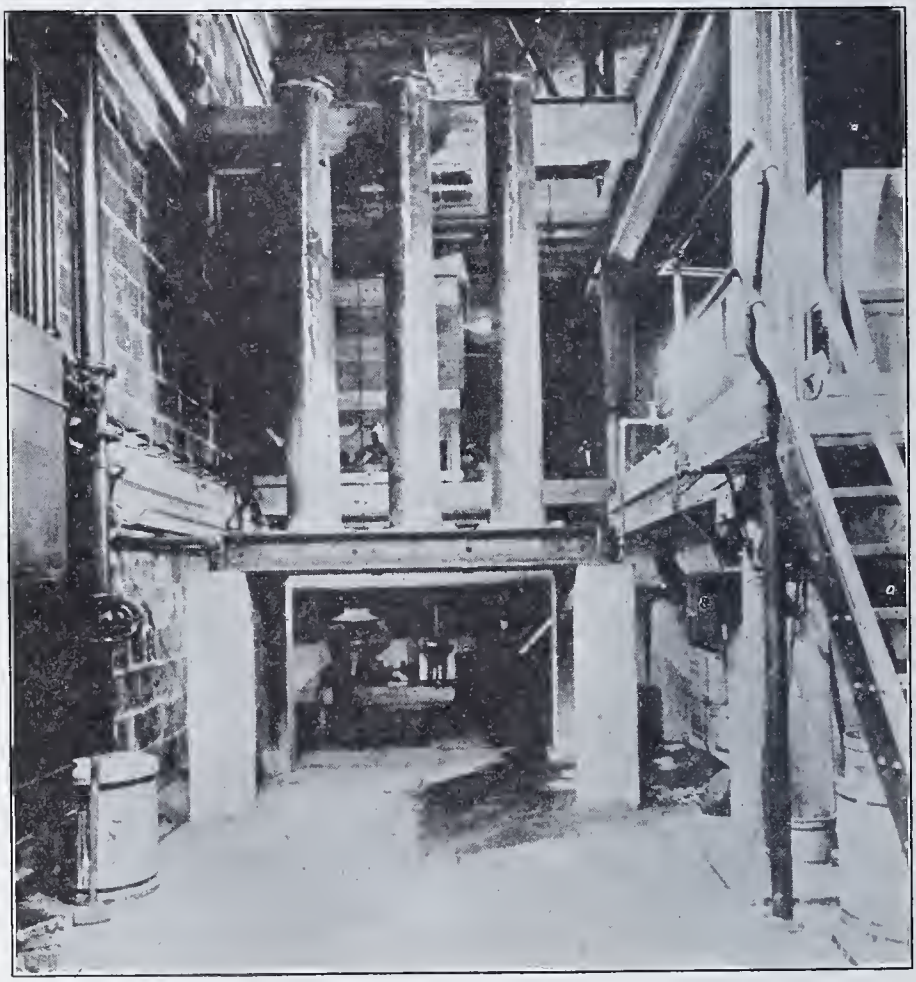


Fig. 9

decomposition be brought about throughout a mass of coal which is, say, 14 inches in cross section, and which is to be subjected at no point to a temperature in excess of 750°C. or 800°C.?

The method devised is as follows: There is first a conditioning stage in which the coal is brought up to a temperature within from 25 to 50 degrees of the softening or pasty stage. This is accomplished in a closed rotating drum which also serves as a heat exchanger for the spent gases from the retort flues. The time element in the preliminary stage is flexible, a quick heating over a period of 15 minutes gives equally good results with the use of a

FIG. 10

Fig. 11

period four or five times as long. From this stage the coal is poured into a retort already heated to the maximum temperature to be employed, approximately 750°C. In this stage the conditions as to time are very exacting. The average time temperature curve shows the heat to have penerated to the center of the mass in from 10 to 30 minutes, under which condition there will be found a resulting coke which is dense and strong, with all the attending advantages of reactivity and character of by-products so greatly desired and only attainable by absence of excessive temperatures. Material thus produced is substantially free from breeze, and needs only to be crushed and sized to be brought into form for domestic use, for which it is peculiarly fitted not only because of its smokeless character in combustion but also because of its ease of ignition, retention of fire and ready response to the control mechanism which accompanies the ordinary house-heating appliance, including especially the open grate.

Not the least gratifying result in these experiments has been the fact that the very large class of coals in the mid-continental

area, ordinarily classed as non-coking, lend themselves admirably to the process. These coals already noted are true bituminous in type, but have a free water content at the mine of from 8 to 16 per cent. This fact and the peculiarly delicate or unstable character of the bonding material for producing the coke structure makes it impossible to produce a dense hard coke at low temperature without following a procedure that recognizes these peculiarities and which, as a matter of fact, may turn them to advantage in securing the results desired.

DEVELOPMENT IN LOW TEMPERATURE DISTILLATION OF COAL AT FAIRMONT, WEST VIRGINIA

By C. V. McIntire
Consulting Engineer, New York

An artificial anthracite of good quality sold at a price lower than anthracite and available in ample quantity offers a solution of the smoke problem. The manufacture of artificial anthracite offers the producer of bituminous coal an outlet for his coal; it opens a new field free of rapid price fluctuations where the demand is constant. Many bituminous coal producers of this country have recognized the possibilities of this field for some time. Many of them have invested large sums in investigating processes and in actual experiments for the development of new methods for making artificial anthracite or for the low temperature carbonization of bituminous coal. Within the last five years half a dozen specific instances could be recounted in which bituminous coal producers have financed experimental work in the low temperature carbonization of their coal.

Among those whose vision and foresight led them to believe in the present and future need of an artificial anthracite is Mr. C. W. Watson, President of The Consolidation Coal Company. He not only realized the need of it, but he felt that a method could be found to manufacture it. His thought was corroborated by the opinion of Coverdale & Colpitts, Consulting Engineers, after an exhaustive examination and a most complete report. Accordingly, Mr. Watson organized, in 1922, the Consolidation Coal Products Company as a subsidiary of The Consolidation Coal Company for the purpose of perfecting apparatus and methods for making such fuel. A program was adopted and a plant was built at Fairmont, West Virginia, under the direction of Coverdale & Colpitts with the writer in charge of operations in the field.

By arrangements with the International Coal Products Company, their process—known as Carbocoal—and their methods were secured to form the basis for the Fairmont development. Operations began in

1923 and have continued up to the present time. The process, together with new apparatus designed by the writer, has been brought through the experimental stages to a successful conclusion, and the owners are now ready to proceed with the erection of a commercial plant.

The Process and the Fuel

Anthracite in an earlier state was bituminous coal. But, under centuries of heat and pressure brought on by geologic changes, the volatile portions were reduced, and the density increased. Obviously, the best method of converting a smoky bituminous coal into a smokeless artificial anthracite is to employ Nature's methods: Heat and pressure. Nature's treatment could hardly be duplicated exactly, but its system was followed as closely as possible in the Consolidation Coal Products Company development.

Instead of applying pressure and heat simultaneously, the Fairmont plant, using the old Carbocoal process as a basis, first treats the coal by low temperature carbonization, then takes the semi-coke residue or char and forms it into briquettes by means of pressure and, finally, reheats the briquettes to render them dense and smokeless. There are the three distinct stages: Low temperature carbonization, briquetting and reheating the briquettes. The last stage is sometimes called secondary carbonization. Each stage operates independently of the others. The materials are cooled between stages and handled by conveyors.

The first stage yields the usual low temperature by-products: A large quantity of tar, rich gas and light oil. The third stage also produces by-products, but in smaller quantity.

The goal of many experimenters is the production of an artificial anthracite by a process using only heat treatment, but none has succeeded. The reasons for the adoption of the three-stage process at Fairmont will be disclosed in subsequent portions of this paper.

Before disclosing the apparatus and its development and performance, we shall first describe the fuel itself.

Low Temperature Semi-Coke or Char

Semi-coke may be made by the distillation of any type of coal. The temperature of distillation and the character of the original coal determine its chemical and physical properties. Even the method of making it has a decided bearing on its characteristics. It can be made in almost

any type of retort or by any means whereby heat in moderate degree is applied to coal. Heat may be applied directly by flame or carried to the coal by hot gases or indirectly transmitted to it through the walls of a retort. The coal may lie quietly during the coking process, allowing heat to penetrate through from the walls, or the coal may be agitated by mechanical means to facilitate the transfusion of heat from the heating surface into the mass. At Fairmont the semi-coke is made by the latter method. The coal is heated while being agitated, the temperature of the coal mass never exceeding 850°F. The coal first melts into a plastic semi-liquid mass; then, under continued heat application, changes from this semi-liquid phase to the solid semi-coke phase. The stirring motion causes the semi-liquid material to roll into variously sized pellets. These are discharged from the retort in this form without much further change, either chemically or physically. The range in size of pellets, some of which are shown in Fig. 1, is from about 6 inches to 1/60 of an inch. They are not dusty. There is a marked absence of small particles of the dust forming size—1/100 of an inch

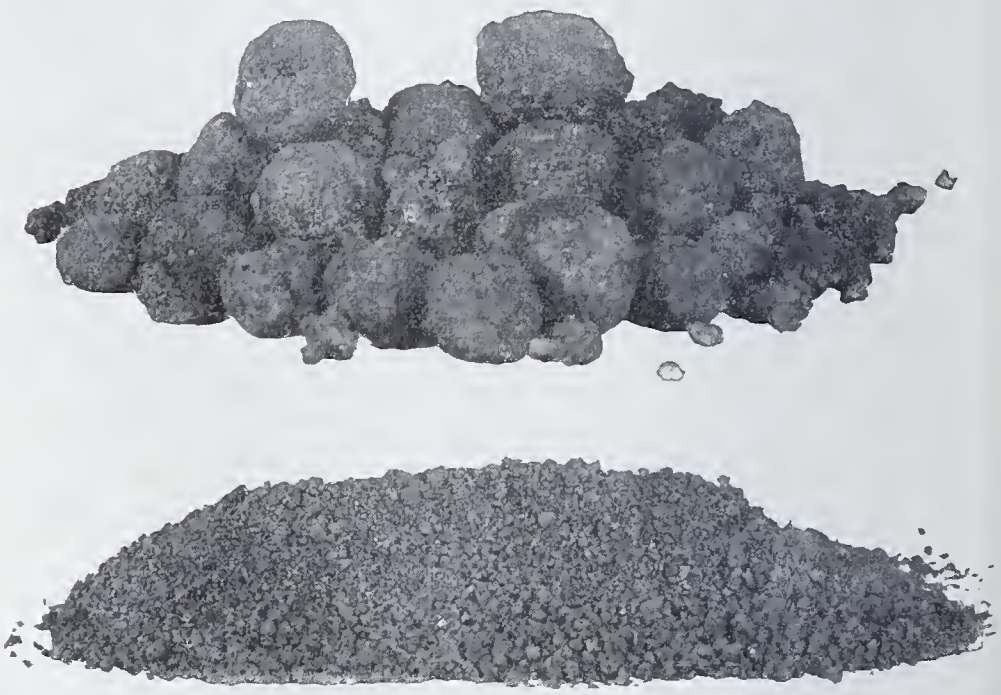


Fig. 1. Semi-Coke. Two Sizes of Pellets

or smaller. These pellets are soft and friable and yield to crushing as readily as coal, with only slightly more wear on the crusher machine parts.

The proximate analysis shows 12 to 14% of volatile matter, and the heating value is 11,000 to 13,000 B.t.u. per pound, depending on the character of the original coal, the amount of ash, etc. Its peculiar soft walled cell structure, its high degree of reactivity and favorable volatile content make it a most readily combustible fuel. Like any form of low temperature char—especially like the well-known lignite char—it has the faculty of igniting easily, and it continues to burn until it is entirely consumed. These desirable properties relating to combustion are in the semi-coke and remain in it after it has been briquetted in the second stage of the process and reheated in the third. They are still found in the final product of the process.

Semi-coke, in the form in which it leaves the oven, has been demonstrated to be an ideal fuel for burning in pulverized coal furnaces in which application it gives higher efficiency than coal itself. It performs well on a chain grate stoker, in gas producers and water gas generators. Successful demonstrations have been made with it in some of the metallurgical processes as well as in the manufacture of furnace or foundry coke in the by-product coke oven serving as a substitute for Pocahontas coal in the mixture charged to the oven.

Briquetting

Semi-coke taken from the low temperature retort is cooled, crushed and mixed with by-product pitch produced from the first stage. It is then formed into pillow shaped pieces about 1½ inches square, weighing about 1½ ounces. These are called briquettes. The pressure used is relatively low—2,000 to 4,000 pounds per square inch. The product is a raw briquette, hard and strong enough to stand the abuses of commercial shipping. It burns well, showing most of the excellent combustion properties of semi-coke, yet it does not fulfill the requirement as an anthracite substitute because its pitch binder gives off an objectionable smoke. If some binder material were available at a low price which would yield a briquette as strong physically as the pitch-bound briquette and which were smokeless, the process could be stopped at the second stage. The raw briquette could then be sold as such and would be an excellent artificial anthracite. But, unfortunately, such binder material is not to be found at a cost within the economic

limits of the process. The pitch binder used at Fairmont is obtained from the process in ample quantity and at practically no cost, for the increase in the value of oils extracted from the process tar, to make the pitch available, equals or exceeds the value of the raw tar.

The Briquetted and Recarbonized Fuel

A secondary carbonization or heat treatment given to the raw briquette removes all of the smoke-forming constituents from the pitch binder and also those which may have remained in the semi-coke. This is done in a special type of oven at a temperature of 1000°F. to 1200°F. The volatile content is reduced to 8 to 12%, and a certain degree of shrinkage occurs which increases the density and strength of the briquette, yet the good qualities of the original semi-coke are retained.

These briquettes, shown in Fig. 2, are smooth and regularly formed, about as large as chestnut anthracite, unaffected by moisture or heat conditions, and strong and hard enough to withstand the abuses of commercial handling. They have been shipped by freight and truck to many points throughout the United States. They have gone through the usual retail channels to consumers and have been found to be quite free from braize and dust. They have been well received by discerning customers and pronounced an

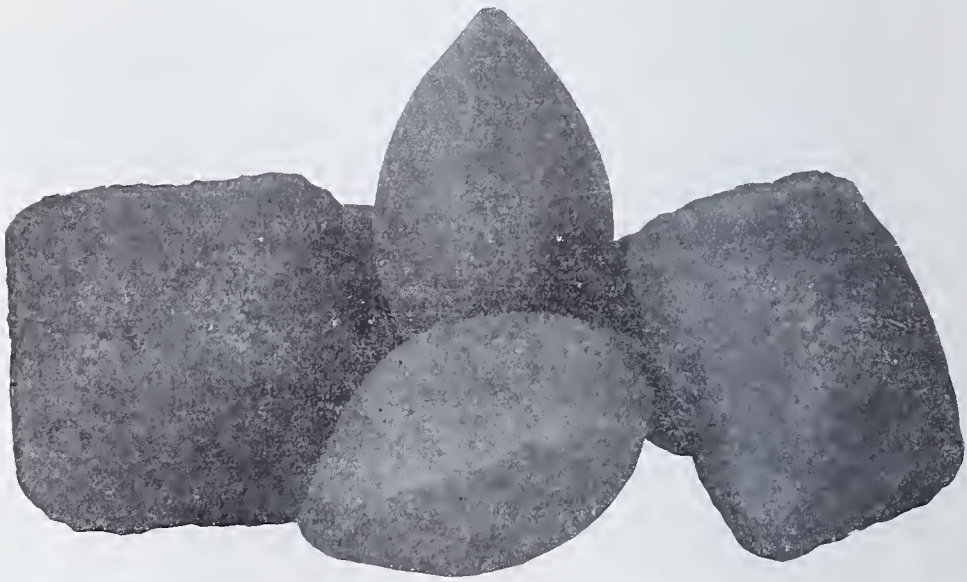


Fig. 2. Semi-Coke Briquetts

excellent artificial anthracite. For use in household equipment, such as heating furnaces, stoves, ranges and fireplaces, the fuel has all the essentials of the perfect anthracite but without the slate and other dirt which has recently become a part of that good coal. They ignite readily, burn with very little draft and respond quickly to draft changes. They will give almost any degree of temperature desired. They hold fire for long periods and retain their shape until entirely consumed.

Description of Apparatus

The distillation of coal either at low or high temperatures is purely a mechanical problem. The chemistry of carbonization is interesting, but has little bearing on the main issue, for, if the mechanical actions are worked out properly, the chemical reactions have a way of taking care of themselves. When coal is distilled at low temperatures by heat transmitted through the walls of a muffle or retort, there is a relatively small temperature head available to force the heat into the coal. Transmission of heat from the wall to the center of the mass is particularly slow due to the combination of low temperature gradient and poor conductivity of the coal itself. To overcome this difficulty the retort at Fairmont employs a mechanical system of stirring or agitation to bring the coal particles in contact with the hot walls and accelerate heat transfusion. This agitation, as it is done at Fairmont, is a simple mechanical solution of a very troublesome problem. Contrary to what might be expected, the power requirement is quite low, costing about 10 cents per ton of coal processed. The direct benefit from the agitation is shown in the remarkably high carbonizing capacity of the retort: namely, 50 tons of coal per day, or about 14.5 pounds of coal per hour per square foot of heating surface. The latter figure compares favorably with the unit capacity of the modern high temperature coke oven—2 to 3 pounds of coal per hour per square foot of heating surface.

The retort is a machine. It must be taken from service periodically for inspection, cleaning or repairs, and was designed with that end in view. While its moving parts are of heavy, rugged construction, those parts subjected to heat are relatively light, and, therefore, rapid heating or cooling is possible. On many occasions it has

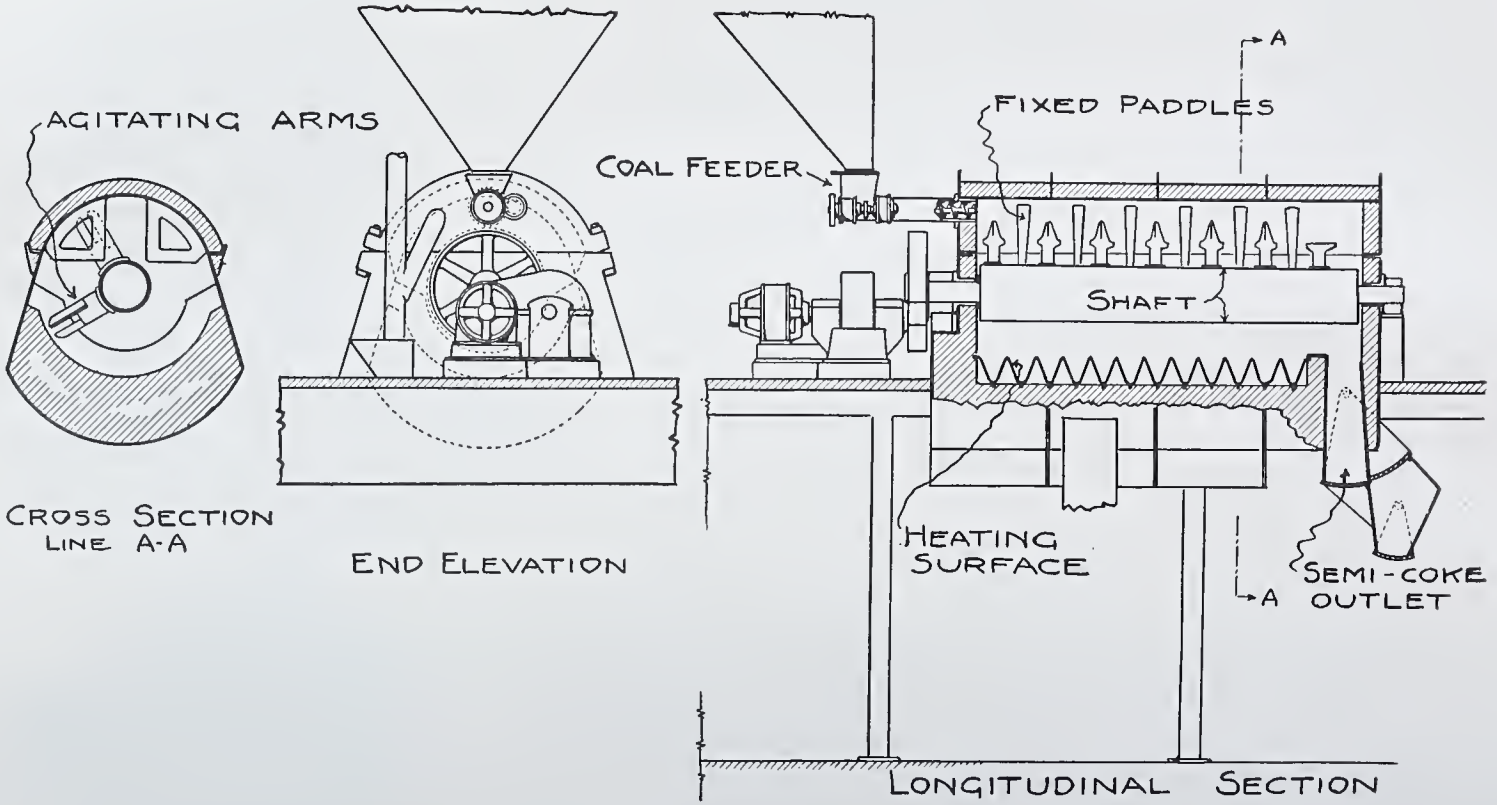


Fig. 3. McIntire Low Temperature Retort

been taken from service, cooled, opened, cleaned, reheated and put into service again within 24 hours. The rated schedule of operation is 21 to 28 days in service with intervening idle periods of 2 to 4 days, or a performance ratio of 80 to 90%. This corresponds to the 80% performance factor of a steam boiler. With a capacity of 50 tons of coal for each day of operation, the average output is 40 to 45 tons. A plant to carbonize 1,000 tons per day would require 25 retorts of the size at Fairmont, 20 in operation and 5 stand-by units.

A general idea of the retort may be obtained from the drawing in Fig. 3 which gives an elevation and cross sections, and shows the steel plate setting or cradle, which forms the retort proper, mounted upon structural members. This is lined below the center with fire brick which serves as a support for the heating surfaces and within which are the channels for preheated air and waste products of combustion. A roof member, comprising the upper half of the setting, is made of light steel plates covered with insulating material and may be removed in one piece to give access to the interior. The agitator shaft extends horizontally through the center of retort and consists of a large steel pipe of heavy section on which are 13 radial paddles arranged in two rows 90° apart. An oscillating motion given to the shaft by a reversing motor and a gear train sweeps the paddles over the heating surface. This agitates the coal which enters the retort continuously from the screw device shown at the left and causes it and the semi-coke to progress toward the discharge end (the right side in the picture). Semi-coke passes continuously into the discharge hopper and is withdrawn at intervals into a lower hopper where it is cooled with steam before being dumped. The metal heating surface is arranged in the form of a corrugated half cylinder, 8 feet in diameter and 15 feet long. The corrugations which extend crosswise of the retort permit unrestrained expansion in all directions. They increase the effectiveness of the heating surface by increasing the surface itself and by applying the heat to the heart of the coal mass. Each of the twelve sections may be separately removed for repairs or replacement, and each forms a separate heating flue accessible at the ends for heat control. Heat is supplied by gas burners at the flue ends. The flanges of the sections supported on the fire brick backing are made

tight by fire clay joints which are saturated with carbon from the gas and effectively sealed thereby. A series of gas-tight tension members keep the sections in place.

There is a crosswise groove between each pair of sections, and each groove has a paddle mounted upon the central shaft which agitates the coal. The paddle, moving through the groove as the shaft rotates, ploughs a V-shaped furrow, and the material thus pushed along scours the heating surface and keeps it clean. This practically eliminates the formation of carbon, one of the troublesome features of previous designs of muffle retorts.

As previously stated, the agitator shaft consists of a large steel pipe. It has bearing trunions at the ends which extend through the retort walls. Each of the thirteen radial paddles consists of a heavy metal base member and a pair of structural angles. The latter are fashioned to fit the corrugation groove through which they travel, and, as wear occurs, they are periodically built up by the electric arc process. One set of paddles lasts indefinitely. Those of the

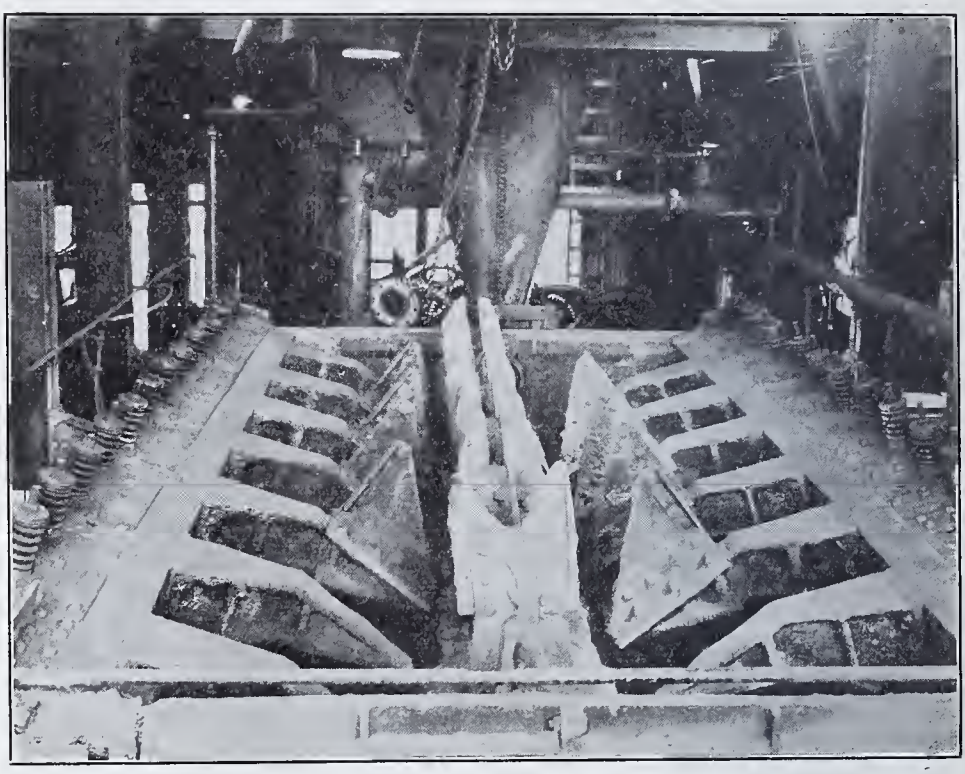


Fig. 4. McIntire Retort With Cover Removed

Fairmont retort are shown in Fig. 4 at the end of the first year of operation, the original paddles being still intact. An important feature of the retort is a series of stationary wiping arms suspended from the cover and so arranged that each row of moving paddles passes a row of stationary arms at each turn. This feature is necessary when treating a full bituminous coal such as the Pittsburgh seam, which melts into a pasty mass during the distillation. The stationary arms comb the pasty substance from between the moving paddles and keep them clean. The system has worked very effectively at Fairmont.

Distillation gas leaves the retort through a conventional standpipe and is cooled and cleaned in the ordinary way.

Briquetting Apparatus

The briquetting department installed at Fairmont and put into operation in 1925 is a conventional layout employing a grinding mill, a fluxer and a Belgian type roll press. A tar still installed as an accessory delivers warm pitch to a tank at the briquette plant from whence it is pumped directly to the fluxer. From the press the raw briquettes are delivered by belt conveyor to the secondary oven. The storage tanks and briquetting building may be seen in the left hand portion of Fig. 5.

Secondary Oven

One of the main difficulties with the old Carbocoal system was the inadequacy of the secondary oven. This unit consisted of an

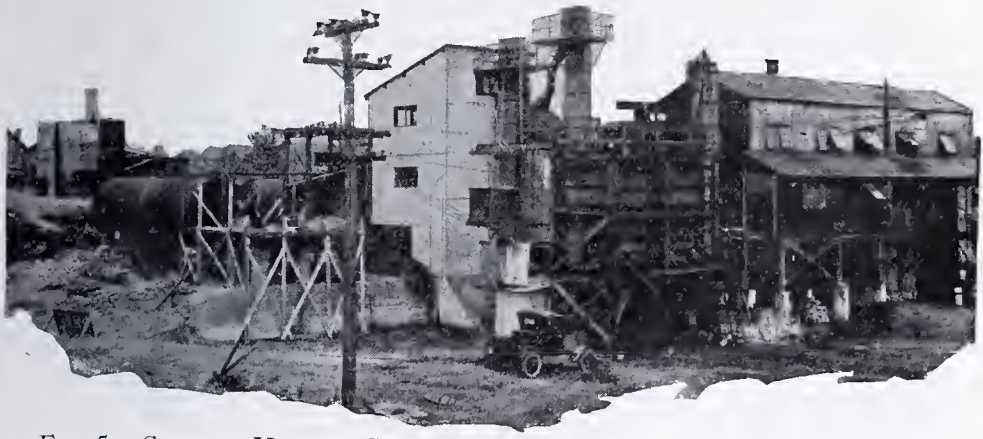


Fig. 5. General View of Consolidation Coal Products Company Plant at Fairmont, West Virginia.

inclined oven 16 inches wide which was intended to carbonize the briquettes at 1800° to 2000° F. and to reduce their volatile content to 3% or less. The briquettes frequently disintegrated due to the shock of contact with the hot walls and formed into a solid mass which could be removed from the oven only with great difficulty. Other grave mechanical troubles developed, and the method was abandoned.

At Fairmont the problem was to devise a method that would carbonize these briquettes without undue shock from high temperatures. An intensive series of experiments showed that the heat treatment required by the briquettes could not be obtained in internally heated retorts by using hot inert gas as a heat carrier. Several large scale units of this type were built and operated for months in various ways without success. A tunnel kiln was built and tried and abandoned on account of the mechanical difficulties of repairs and maintenance. Finally, a new principle was devised. A horizontal layer of briquettes, two briquettes thick, suspended on a metal tray, was exposed to radiant heat from the roof and floor of an oven for thirty minutes. With the roof and floor temperature at 1200°F., the 30-minute exposure gave just the required degree of carbonization. Applying this principle, a number of small ovens were built and successfully operated. From the performance of these, plans were drawn for the commercial size unit which was built and put into operation in February, 1926.

This commercial carbonizer consists of five horizontal ovens placed one above the other in a fire brick bench with hollow arches between ovens. Heat generated by a gas burner system in the arches is applied by radiation to the briquettes which are carried on metal trays suspended midway between the floor and roof of each oven. The trays are withdrawn and reloaded by an operating mechanism which travels vertically in front of the bench. This machine opens an oven door, withdraws a tray, dumps the briquettes therefrom, returns the tray to the oven and, at the same time, loads a fresh charge of raw briquettes upon it. Upon the closing of the oven door the machine moves into position before the next oven in readiness for another discharge. The carbonized briquettes are dumped into a pan of water and removed after being sufficiently quenched and are then taken by belt conveyor to the railroad cars.

Fig. 6. Briquette Carbonizer

The carbonizing capacity of this retort is high—about 10 pounds of briquettes per hour per square foot of heated surface, which also compares well with the 2 to 3 pounds capacity of a by-product coke oven. The oven has other advantages. The briquettes are well carbonized with practically no breakage. The temperatures are under close control both by the regulation of gas burners and by the amount of time allowed for the briquettes to remain in the ovens. There is a minimum loss from radiation. The heat in the trays is conserved, and there is the smallest possible amount of outside radiating surface. All ovens are accessible through the doors for patching or repairs, or for the removal of carbon. Any oven can be removed from service while the balance of the bench is in operation, and trays can be removed and set aside for renewal or repairs. This unit is illustrated in Fig. 6. After about eight months of operation certain defects appeared in

the arches of the carbonizer. Another bench was designed in which this detail is improved, and it is now under construction.

Performance of the Apparatus

It should be borne in mind that the apparatus herein described is of commercial size. A full commercial plant would consist of a number of low temperature retorts and briquette carbonizers of about the same size as those now in operation at Fairmont. The by-product yields and other operating results are exactly those which may be expected from a large commercial undertaking.

The low temperature retort has been in operation since August, 1924, more than two years. Its performance has been interrupted a number of times to make alterations. Its original length of 25 feet was cut down to 16 feet, 3 inches, and again to 15 feet. Its heating system was completely revised on one occasion and then rebuilt in its original form. Shut-downs were made for insertion of various types of heating elements. It has demonstrated over long periods a safe capacity for treating 50 tons of coal per day, and its total record is about 22,000 tons of coal processed.*

The retort produces the following products from one ton (2,000 pounds) of 36% volatile Pittsburgh Seam coal: 1,480 pounds of semi-coke; 31 gallons of low temperature tar of 1.084 specific gravity.; 2 gallons of light oil; and 3,000 cubic feet of 950 B.t.u. gas.

The briquetting plant was put in operation in September, 1925, and has produced about 9,000 tons of raw briquettes made from semi-coke. Of this quantity, about 3,000 tons have been put through the briquette carbonizer. A part of the carbonized briquettes are shown in the photograph (Fig. 7) of the stock pile. The secondary carbonization of the briquettes yields about 2,000 cubic feet of 450 B.t.u. gas and 8 gallons of high gravity tar per ton.

Coal Testing Apparatus

In addition to the usual chemical laboratory facilities, the Fairmont plant is equipped with two new types of coal testing or assay furnaces which were designed by the technical staff. One is an intermittent retort of 50 pounds capacity, and the other is a continuous retort with

*A report of coal tonnage and by-product yields from this plant may be found in a paper by Horace C. Porter in 1926 Proceedings of American Gas Association.

a capacity for about one ton of coal per 24 hours. Both are equipped with motor-driven, internal agitating devices similar to the large scale retort and both have lead-lined jackets which permit close control of temperatures. These units have been used to check the performance of the large scale retort and a large amount of valuable data has been derived from them.

Fig. 7. Carbonized Briquettes at Fairmont

DISTILLATION OF COAL; INTERNAL HEATING; THE L. & N. PROCESS

(Laing & Nielsen)

By Harald Nielsen
Sensible Heat Distillation, Ltd., London, England

Introduction

The devastating coal strike in England has brought home to every thinking man and woman in every civilized country the vital importance of coal and fuel resources, or rather, the efficient utilizing of same as the main factor in the whole of the industrial well-being of the community.

Cheap fuel means cheap heat and power, low manufacturing costs, cheap transit and successful competition.

Cheap fuel does not necessarily mean that the cost of digging the fuel out of the bowels of the earth should be very low; if it is, all the better; but what it does mean is that a careful scientific selection of the availability of the various products obtainable is made, and that only the products, or let us say, heat units, are selected for the process work for which they are economically most suitable.

Everybody, whether of a scientific turn of mind or not, has some ideas about the burning of raw coal being wasteful, preventing the ultra violet rays from doing their beneficial work for mankind, etc.

Heat units, whether they be solid, liquid or gaseous, have different scopes and ramifications and different values depending upon their availability. Raw coal contains them all, solid, liquid and gaseous heat units.

Let us take the price per therm, or 100,000 B.t.u.'s of various fuels, which the average industrial consumer has to pay in England:

Table I.

I.	Raw coal @ 17/6 @ 12,500 B.t.us. per lb.	o.777d. per therm.
II.	Fuel oil @ 70/– @ 16,500 B.t.us. per lb.	2.270d. " "
III.	Diesel oil @ 90/– @ 18,000 B.t.us. per lb.	2.670d. " "
IV.	Petrol @ ½ per gallon.	9.825d. " "
V.	Town gas.	7.500d. " "
VI.	Producer gas.	1.443d. " "

Taking the raw coal therm as the unit and allowing for greater efficiency in converting the respective heat units into power (average, well established practice) we have:

TABLE II.

I.	Raw coal.	1.000 Ratio Costs.
II.	Fuel oil.	2.490 " "
III.	Diesel oil.	1.755 " "
IV.	Petrol.	6.475 " "
V.	Town gas.	4.940 " "
VI.	Producer gas.	0.952 " "

These figures show that for some reason or other, greater convenience, ease in obtaining supplies, etc., consumers are willing to pay so much more for the heat units in the form they desire.

I said above that raw coals contain heat units in all the various forms, and I will now add that by proper scientific treatment coals can be made to yield these, and, therefore, it boils down to this: that by taking credit for the more valuable heat units, the cheaper heat units obtainable as a solid residue can be made still cheaper, benefiting the manufacturer and consumer by the saving thus effected.

Furthermore, the solid residue can be made in a form rendering it available for purposes which could formerly not be imagined.

We have now to consider the following questions:

I. The correct scientific principles of treatment.
II. The costs of the treatment or conversion.
III. The producing of the best solid, liquid or gaseous products, or in other words, the products for which the highest possible economic prices can be obtained.

For a number of years the group with whom I am associated have been conducting work along certain lines. These lines, we are convinced, open out new vistas, and by giving a brief account only in the time allotted to me I hope to be able to indicate to you that we had some justification in our departure from the stereotyped lines followed by so many other investigators.

There is a vast scope for properly conducted investigation on sound lines on coal and oil shale. One need only glance at the very recent report of The Federal Oil Conservation Board on the natural well oil resources and the shortcomings of these in the next decade

to realize that the only reserves civilization can throw into the breach are the scientific handling and distillation of coal and shale to supply the products not longer obtainable directly from a bore hole in the ground.

The Correct Scientific Principle

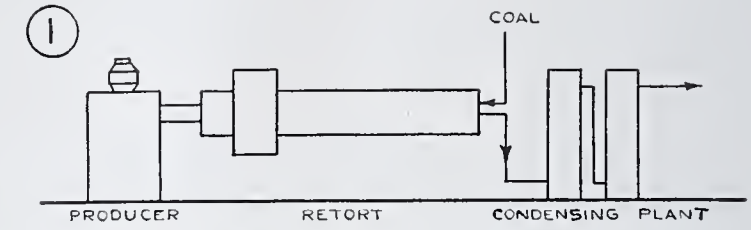
Very early in our work we realized the futility in following the crowded, beaten track of general investigations. As everybody else, we were up against the poor heat conductivity of coal; the unstability and multitude of the distillation products of coal; the uncontrollable thermal decompositions; in short, the ignorance of the very fundamentals of coal. We made up our mind to tackle the problem of the poor heat conductivity of coal first. The physical property we could not alter; but bearing in mind that to force a given amount of heat into a given quantity of coal to effect a thermal change, the work to be done is a product of temperature difference, time, surface and conductivity. The temperature difference we cannot alter with impunity, without upsetting the products we desire to obtain. The conductivity is a specific factor which is beyond our control. We can play with time and surface; but since the surface is the easier to modify, we decided to bring down the distillation time as far as practically p,ossible, 2 to 2½ hours, and increase the surface to carry the brunt of the battle. To take full advantage of the surface possibilities offered, it is evident that a gaseous distilling medium should be employed. This medium can at will be altered in volume, composition and temperature to suit any conditions. It could be producer gas, blast furnace gas, water gas, combustion gases, in short, any gas not containing a perceptible percentage of free oxygen. The retort or kiln could be of the simplest imaginable construction—a slowly revolving, firebrick lined tube through one end of which the raw coal to be distilled enters, traveling in counter-current with the hot gas entering the opposite and lower end. The rotation, in conjunction with the inclination, transports the coal forward continuously through gradually increasing temperature zones.

The speed of coal travelling can be altered by modifying the speed of the retort, or the inclination may be altered, so here we have the means of adjusting and regulating all the factors just to suit any particular set of conditions. We are no longer depending upon the

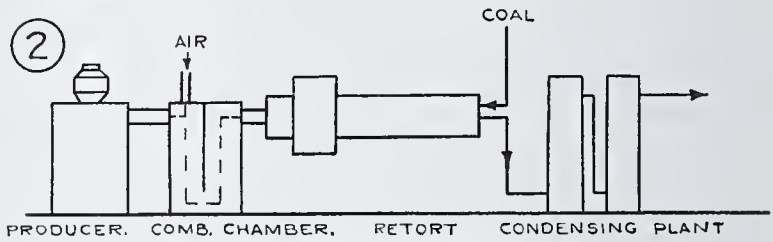
good will of the coal to behave or not to behave. We avoid cracking of the primary oil product, since the counter-current principle of distillation is employed. Any distillation products, set free at a specific temperature, are at once swept into zones where lower temperatures are prevailing. Furthermore, the large volume of gas employed lowers the vapour tension of the oils, and it is found that the oils are set free at temperatures at or below their initial boiling points.

We soon observed that the whole *modus operandi* could be condensed into the following few lines for general distillation conditions, and primary oil production in particular:

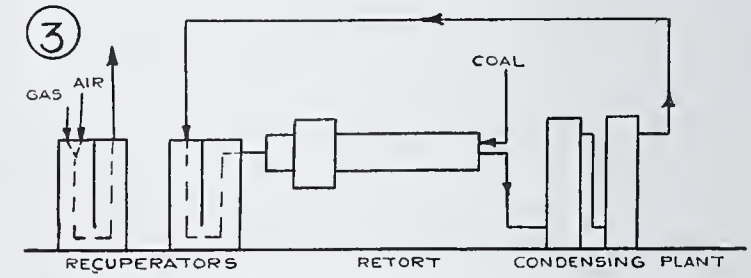
1. Internal heat solely, or, if external heat is used, so large a volume of protecting gas or steam must be admitted that the oils set free do not get into contact with any surfaces or zones of temperatures higher than those at which the oils were evolved in the first instance.
2. The heating must be counter-current to the flow or passage of the coal.
3. The distillation products must be removed in strict uniflow with the heating gas current.
4. Sufficient volume of gaseous heating or protecting medium must be present to lower the vapour tension of the heaviest fractions to such an extent that no condensation takes place within the retort at the temperature prevailing in the coldest zone.
5. Sufficient so-called free space or gas space must be available to secure a free passage of the oil vapours without these being forced to penetrate through colder layers of raw material.
6. Preferential preheating of the raw coal entering to temperatures above the dew-point of the oil vapours.
7. The process of distillation must be continuous.
8. The process must be under complete temperature control.
9. The process should permit modifications in regulation of coal feed, duration of distillation, and volume of distilling medium, independent of one another.
10. The process should be such that the composition of the distilling medium, and the temperature, can be modified and controlled independent of the retorting.
11. The source of heat must be altogether separate from the retort.



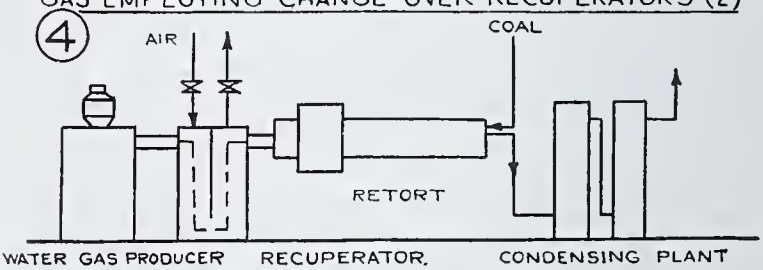
DISTILLING BY UNIGNITED PRODUCER GAS



DISTILLING BY IGNITED PRODUCER GAS OR OTHER COMBUSTION GASES.



DISTILLING BY MEANS OF A RE-HEATED CIRCULATING GAS EMPLOYING CHANGE OVER RECUPERATORS (2)



DISTILLING BY MEANS OF SUPERHEATED WATER GAS USING THE COMBUSTION OF THE BLOW GAS TO HEAT RECUPERATOR (1) INTERMITTENT

FIG. 1

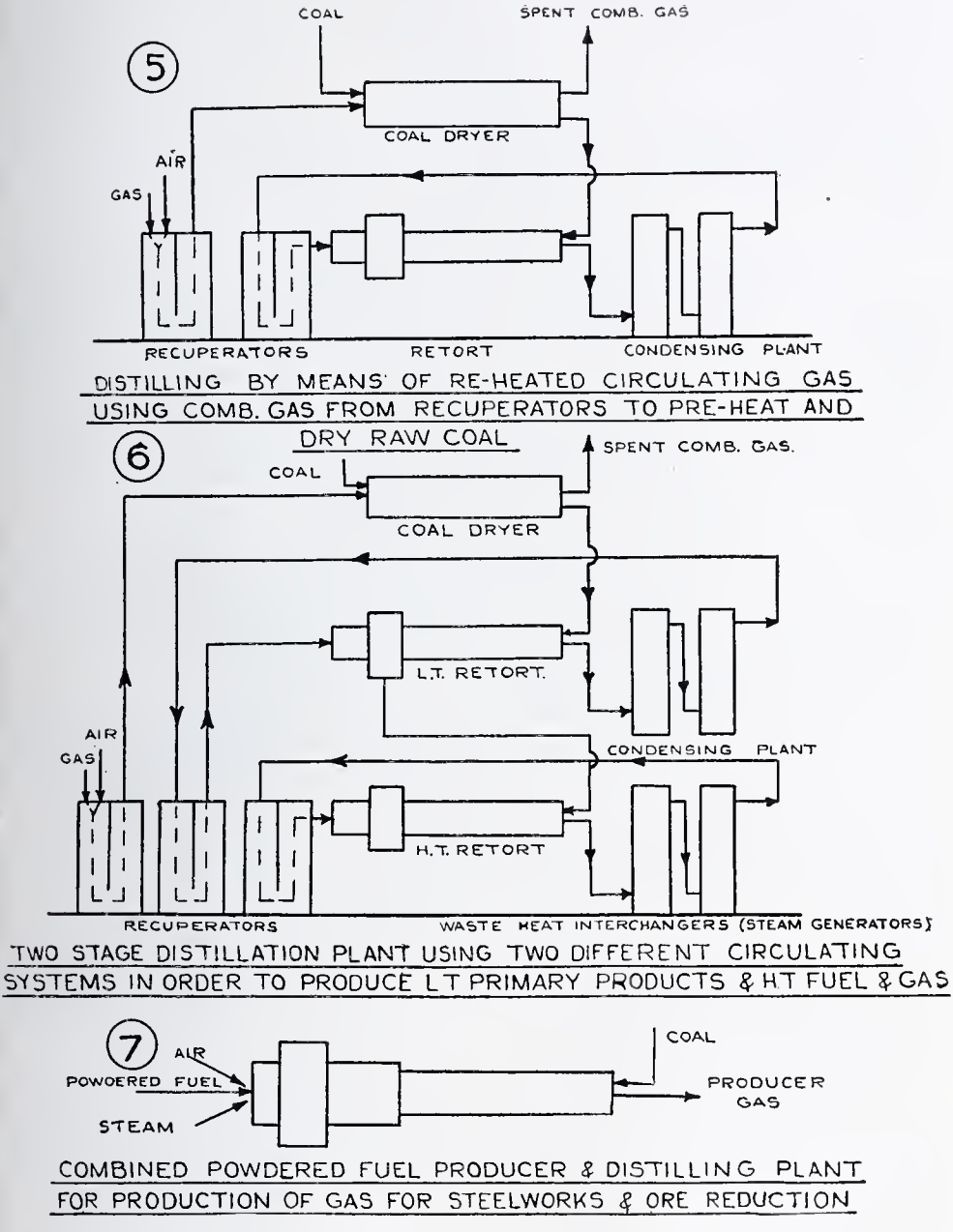


FIG. 1.—CONTINUED

12. The largest possible single units should be employed, in order to secure steady running conditions and uniformity of output.

We have found that our later work has confirmed these points, and we have nothing to add to these.

To illustrate the various combinations and computations possible when employing a gaseous distilling medium in direct contact with the raw coal in a rotary retort, Fig. 1 with subsections 1 to 6 will serve.*

Generally speaking, investigations and results obtained along small scale experiments or laboratory plant have been extremely difficult to transfer to large, commercial scale units. In dealing with coal the difficulties have been greater perhaps than in any other branch industry.

As long as external heat is employed, the difficulties will always remain.

In laboratory practice a few grams of coal, 15 to 20, are heated in a silica or hard glass tube, duration about one hour (assay of coal for carbonization purposes, The Fuel Research Board's Technical Paper No. 1). The quantities of solid, liquid and gaseous products are measured.

Large scale tests dealing with some hundredweights, or tons, are then carried out, and although reasonable agreements as to the weights of solid residue and volume of gas may be obtained, the oil and liquor yield are quite different, as a rule only 55 to 60% of those obtained during the assay, and as far as similarity of oils is concerned, no information whatsoever can be co-related. The reason is not far to seek. There is no similarity in the time factor, the temperature gradient is widely different, retort material is different, in short, a thousand and one factors are at play of which the operator can have no idea.

The aluminum apparatus, according to Prof. Franz Fischer, dealing with larger quantities, up to 200 grams of raw coal, is certainly far more satisfactory, and Fischer's rotary retort still more so; but external heat is external heat, and the temperature gradients are different.

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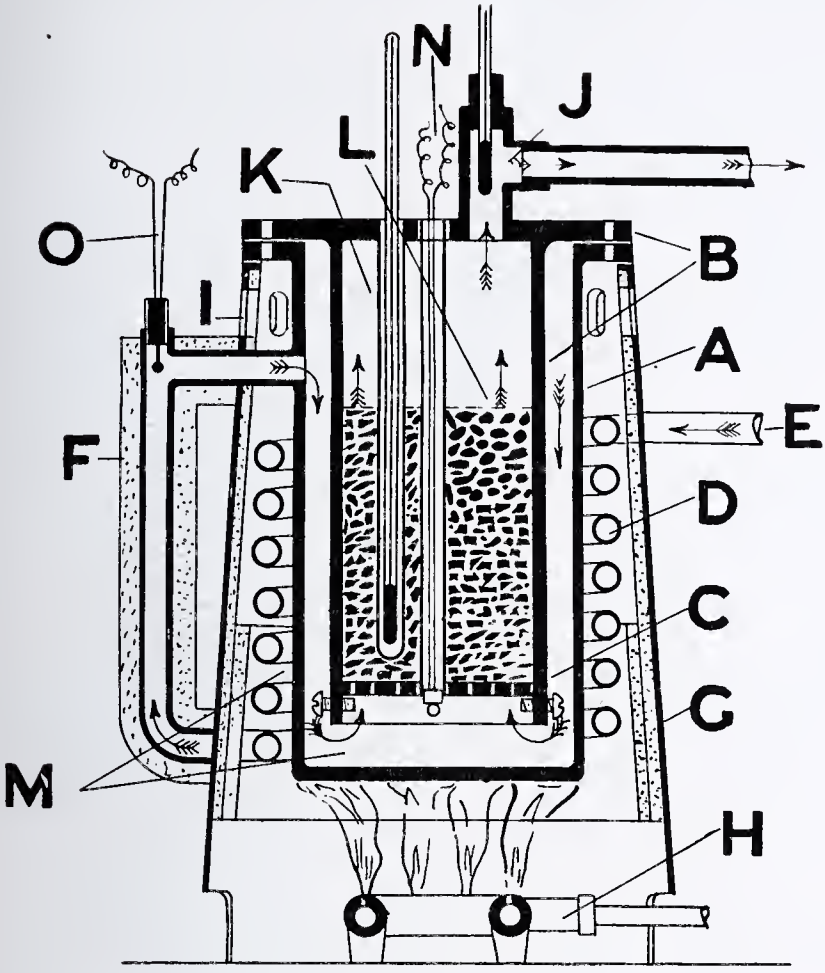
*Further, a somewhat abbreviated list of technical journals and books in which accounts of some of our work has appeared from time to time is appended, in order to assist those interested in particular sections.



A	RETORT CONTAINER	I	EXIT FOR COMBUSTION GASES
B	RETORT WITH TOP COVER	J	EXIT FOR DISTILLING MEDIUM & DISTILLATION PRODUCTS
C	PERFORATED FALSE BOTTOM	K	THERMOMETER POCKET
D	SUPERHEATING COIL	L	FINE WIRE GAUZE
E	INLET FOR DISTILLING MEDIUM	M	FINAL SUPERHEATING SPACE
F	OUTLET FOR SUPERHEATED MEDIUM	N	THERMOCOUPLE
G	ASBESTOS LINED CASING	O	THERMOCOUPLE
H	GAS BURNER		

FIG. 2

We realized that if laboratory tests should form a guidance for large scale work they should be carried out under conditions approaching those of a large plant as closely as possible, and we set out to evolve our assay method. After four years' work, during which 125 assays were carried out, and figures compared with those obtained by distilling many hundreds of tons of coal, we have satisfied ourselves that it is possible to obtain data from smaller scale tests of real use.

We employ the sensible heat of the same kind of gas, the same time factor, the same temperature gradient, rate of heating, etc., and we employ much larger samples, from 600 to 1,000 grams per charge, so that a sufficiently large quantity of solid residue, oil and gas can be obtained for further examination.

The apparatus is quite inexpensive, easy to construct, extremely simple and reliable in operation. We estimate the life of each assay apparatus to be well over 200 assays.

Fig. 2 illustrates the apparatus and will be clear without further comments.

Note: A number of these assay apparata are in use in the Fuel Research Laboratories in England and on the Continent.

Selecting one of our typical coal tests at random will perhaps speak clearer than words.

Table III gives the analysis of the raw coal.

TABLE III.

Name of Coal: Rossington Main Slack, Barnsley Bed Seam.
Coking Properties: Slightly Coking, rather friable.

AS RECEIVED:		ASH AND MOISTURE FREE:	
Moisture.	4.80%		
Volatile Matters.	28.70%	Volatile Matters.	38.50%
Fixed Carbon.	45.76%	Fixed Carbon.	61.50%
Ash.	20.74%		
Carbon (dry basis)	62.27%	Carbon.	80.72%
Hydrogen "	3.76%	Hydrogen.	4.80%
Oxygen "	9.02%	Oxygen.	11.55%
Sulphur "	1.09%	Sulphur.	1.39%
Nitrogen "	1.21%	Nitrogen.	1.54%
Ash "	21.65%		

Calorific value as received: 11,000 B.t.u. per lb. = 6,120 kg. cal. per kg.

Carbon Hydrogen Ratio C/H.....16.80.

Table IV gives the data from the comparative assay and large scale tests, calculated on dry basis (ton basis).

TABLE IV.

	ASSAY TEST	LARGE SCALE TEST
Quantity of coal dealt with	0.0006 Tons.	20.53 tons.
Solid residue, dry basis.	0.744 ton.	0.732 ton.
Oil.	16.5 gallons.	16.4 gallons.
Gas.	1,870 cub. ft.	2,800 cub. ft.
Temperature max. in end of oil zone.	545 °C.	550 – 555 °C.
Temperature max. to which solid residue has been exposed.	560 °C.	620 °C.
Volatile matters in solid residue.	9.80%	8.60%
Duration of distillation.	100 minutes.	120 minutes

ELIMINATION OF FISCHER FRACTIONS
(Petroleum Ether Soluble Neutral Oils)

Fraction 200-300°C. Specific Gravity	0.900.	0.900.
Fraction above 300°C. Specific Gravity	0.970.	0.968.
Petroleum ether solubility of fraction above 300°C.	Complete.	Complete.

The above tables show that irrespective of the size and capacity of the plant the yields per unit of weight agree closely, taking into consideration the somewhat higher temperature to which the solid residue in the large scale plant was subjected after the oils had been expelled. The tables further show that by applying the very sensitive Fischer test to the distillation products which are most easily upset, namely, the primary oils, these are identically the same in both cases, and that by distillation by means of a gaseous heating medium in counter-current the temperature to which the solid residue is ultimately subjected has no bearing on the primary oils, but only results in the elimination of further volatile matters in the form of gas.

We have carried the volatile per cent of solid residue right

down to 2½ to 3% without the slightest detriment to the primary oils, and without impairing the free and easy ignitability of the residue or reactivity of same.

The Fischer oil test is described fully in Prof. Franz Fischer's Book "Die Umwandlung der Kohle in Oel" and by myself in the June numbers of the Gas Journal and the Iron and Coal Trades Review of this year.

The Fischer test is one which we can state gives a true picture of the conditions of the neutral primary oils and at once indicates whether or not secondary thermal decomposition has occurred.

The Cost of Treatment or Conversion

Let us for a moment consider, briefly, the various items which make up the cost of conversion. We have first of all to consider the capital expenditure per ton of coal handled. The smaller this capital, the smaller the interest figure; the bigger the single unit and the simpler, the cheaper it is to erect and maintain. The coal conveying and distributing plant becomes much simplified, and the same applies to the solid residue handling plant.

The British Fuel Research Board quite recently studied this matter and came to the conclusion that a plant to be successful for English conditions should not cost more than 20/- to 25/- per ton coal distilled per annum, equivalent to 4.8 to 6.0 dollars.

A plant distilling coal in a large rotary retort under the process with which my name is associated costs 4 to 4.05 dollars per ton per annum.

Large single units can be made automatically operated far easier than a great number of small units. We maintain that the correct size units should not be of less than 100-125 tons per twenty-four hours. Large units, therefore, mean less labor costs.

The units should be continuous, as only under these conditions can the unavoidable fuel bill be brought down to its lowest level and uniformity and steady running attained.

To sum up:

Low capital expenditure.

Large single units.

Simplicity in construction.
Low maintenance costs.
Automatically operated.
Elimination of labor as far as possible.
Low fuel consumption.

Translating the above into dollars and basing the capacity of plant on four single "L & N" units, capable of dealing with 150,000 tons per annum, we have: capital cost of plant erected on foundations supplied, $610,000.

The operating costs per ton of bituminous coal (2,240 lbs.) are:

12½% on capital as maintenance and interest	$0.5082
Labor: 12 men per shift of 8 hours, 1 Foremen, Superintendent	0.2500
Water supply, pumping costs	0.0121
Lubricants, general stores, minor repairs, etc	0.0535
Power, 1 cent per K.W. hour	0.1520
Fuel @ $2.00 per ton	0.2430
Total operating costs per ton	$1.2188

The figures are very carefully considered figures, and are based on operations through several years on a considerable scale, and cost price of same is the one at which British makers are prepared to erect and guarantee the plant.

The Production of the Possible Products

(a) Solid residue.
(b) Liquid (oils) Products.
(c) Gaseous Products.

Owing to the inherent nature of coal, which we have been rather slow to realize up to within the last few years, the retorting part of the processes generally has been asked to do too much.

Broadly speaking, the retort was requested to produce the hardest and densest solid residue, all in saleable lump form, the biggest quantity of liquid, i. e. oily products, in a form which would leave Pennsylvania well oil far behind, and, finally, the largest volume of the highest calorific value gas.

To this day a vast number of investigators are still working towards this retorting Utopia.

It is perhaps hard to realize that the best working conditions for one set of products, be they solid and gaseous, are deadly detrimental to the other—the oils. It cannot be emphasized with sufficient force that in trying to overreach themselves, the enthusiastic investigators generally manage to spoil everything. Nowhere is general sense of proportion wanted more badly than in the treatment of coal.

The best possible products can never be obtained in one single stage; they must be manufactured, and all the retort should be called upon to do is to effect the most economical and efficient separation from the original raw coal of the best possible raw products, solid, liquid and gaseous, for their further refining and manufacture for the specific purpose for which they are wanted. It is only possible in this way to secure and guarantee uniformity and quality.

(a) *Solid Residue.*

The solid residue may be required for industrial or domestic use.

For industrial or power production, cheapness and suitability come first. It is, therefore, essential to extract everything of higher value, whereby the costs can be brought down. With few exceptions, the size of material does not play any important part; modern chain grate stokers will deal with almost anything, and for powdered fuel burning, the material has to be ground up anyhow. What is of importance is the free and easy burning.

We have found that by carrying out the distillation in such a manner that no graphitic carbon is deposited on the cell walls of the solid residue, the actual percentage of volatile matters left has very little to do with the ignitability. It has been generally maintained that for successful burning in the powdered state 10-12% volatile matters was highly desirable. This is not so. Large scale tests on burning our solid residue have proved the correctness of our contention (see the Iron and Coal Trades Review, June 18, 1926).

Table V summarizes a few facts regarding some large scale tests carried out in the North of England.

TABLE V.

Fuel: "L & N" Solid Residue	From strongly coking coals	From medium coking coals
Moisture up to 105°C.	3.00%	3.17%
Volatile matters.	8.23%	8.09%
Fixed carbon.	72.85%	78.32%
Ash.	15.92%	10.42%
Calorific value per lb.	11,500 B.T.U.	12,100 B.T.U.
Hourly fuel consumption (average).	3,300 lbs.	3,000 lbs.
Thermal efficiency.	83.5%	83.6%
Heating surface of boiler.	5,200 sq. ft.	5,200 sq. ft.
Working pressure.	250 lbs. sq. inch	250 lbs. sq. inch
SIEVING TEST ON POWDERED RESIDUE.		
Retained on 90 mesh.	5.6%	Nil.
Between 90 and 160 mesh.	7.4%	10.5%
Through 160 mesh.	87.0%	89.5%
Average CO_2 in flue gases.	17.0%	17.0%

The type of boiler employed was the well known Woodeson water tube boiler with Clarke, Chapman unit pulveriser.

A previous test was carried out at the same boiler plant very successfully on a powdered "L & N" solid residue containing not more than 4.6% volatile matters.

We have found that the power requirement for grinding the "L & N" solid residue is from 10 to 15% less than that required for the original raw coal.

It is further found possible to produce a standard powdered fuel from our residues from varying classes of coal with the same physical properties, moisture absorption percentage, combustibility, specific gravity (real sp. gr. 1.42-1.45, water being 1.0) and volumetric gravity (round 48 cubic feet per ton).

The space occupied by the powdered "L & N" residue is thus the same as that of raw powdered coal.

This is of importance when considering powdered fuel burning for the Mercantile Marine (see the Marine Engineer and Motorship Builder, August, 1926).

When burning the solid residue on chain grate stokers it has been found possible to increase the thickness of the fuel bed from 4 to 7

inches, without detriment to the overall efficiency, thereby increasing the rated steaming of the boiler by over 50-60%.

A domestic fuel must possess the following properties:

I. Must be smokeless.
II. Clean to handle.
III. Uniformity of size (no smalls).
IV. Low ash content.
V. To stand transport well.
VI. Free burning and easily ignitable.
VII. Uniformity in calorific value and quality.
VIII. As dry as possible.
IX. Must be weather proof.

These demands can only be met by a manufactured article. Only carefully washed or good grades of bituminous coals should be used in order to secure low ash percentage in the solid residue. When distilling coal in a rotary retort, particularly those of the feebly or non-caking kind, by far the largest percentage of ash in the solid residue is found in the fines because a classification takes place inside the retort. The fines may be screened away from the large sizes and used industrially and it will be found that the larger size fuel, above say ½" mesh, contains virtually not much more ash than does the average raw coal. Numerous observations have convinced us of this.

If a strongly coking coal is available, the possibility exists of briquetting during an intermediate stage, at or just before the coal reaches the plastic conditions. This operation must be carried out in a neutral or slightly reducing atmosphere and without too much loss of heat, the briquettes must be re-admitted to the retort to be further distilled in order to remove the largest possible percentage of volatile matters. A blending of non-coking and strongly coking coal can be dealt with in the same manner, thus utilizing the excess coking properties of the one coal.

Pre-oxydizing of heavily swelling coal may be resorted to before heating and compressing, but after all, it does seem a pity to deliberately destroy one of the most valuable properties of strongly coking coal.

In dealing with non-coking bituminous coal purely, hot briquetting under pressure of up to 5 to 10 tons per sq. inch might perhaps pro-

duce a well carrying briquette, but too little work has been done at present to allow any great expectations in this particular direction.

There remains then briquetting with a binder.

Pitch binder briquetting is too well known to deserve further mention. The Carbocoal process, for example, worked along these lines. I have no doubt in my mind that if the primary, as well as the secondary, distillations had been closely studied, and entirely different lines of distillation adopted, the system would have had all the elements of success.

We have made very excellent briquettes using our residue with various vegetable binders, such as Kasawa binders; but the weather proofing does leave something to be desired, particularly for the English climate. We have, however, found that in making ovoid briquettes, and using a pitch binder, 10 to 15% less binder is required for the distilled residue than for the raw coal.

Using modern machinery, the total costs of producing 2 ounce ovoids from distilled residue on a scale of 1,000 tons briquettes a week works out at 65 to 70 cents per ton including all costs baring that of the binder.

The condition of the manufactured fuel market in England is entirely different from that in America. In England the manufactured article must compete with the low priced raw bituminous coal, but in America the competitor is highly priced anthracite. There is, therefore, in this latter country, a far greater margin which will permit a larger expenditure in producing a high grade article.

(b) *Oils*

To be brief when discussing the oil distillates from coal is almost impossible. This particular subject is not only one of the highest scientific interest, but one of the greatest economic importance to countries which do not possess an abundance of well supplies.

Many workers lay particular stress upon the facts that the oils obtained by distillation from coals should be primary products, as it is only possible from these to build further. We entirely agree. All our endeavours have been in the direction of obtaining these, and so find out under what conditions they can be procured. We think that we are now justified in asserting that all neutral primary oils produced from bituminous coals, and even brown coals and lignites, are identical. This is a sweeping statement, but it can be supported. Take

Table VI in which is summarized some comparative Fischer fractions from a great variety of coals, coking, non-coking and lignitic coals.

TABLE VI

Locality of Coal	200-300° Neutral Oil			Above 300° Frac. of Neutral Oil			
	Sp. Gr.	%C	%H	Sp. Gr.	%C	%H	Solubility in Petroleum ether
Durham Coking.	0.902			0.986			Complete
Durham Coking.	0.905	86.55	10.65	0.990	87.23	9.37	Complete
Seaham, Durham.	0.915	86.54	10.63	0.977	86.97	9.35	Complete
Yorkshire Coking.	0.905	86.77	10.97	0.978	87.79	9.97	Complete
Barnsley Seam Coking.	0.915	86.89	10.72	0.960			Complete
Yorkshire Non-coking.	0.908	86.64	11.07	0.970	86.26	9.87	Complete
West Yorkshire Coking.	0.900			0.968			
Scottish Non-coking.	0.910	86.66	10.65	0.975	87.30	10.14	Complete
Canadian Lignite.	0.922	85.53	10.75	0.960			Complete.
German Brown Coal.	0.900	85.96	10.75	0.952			Complete

Note: Allowances have been made for the relatively larger percentages of paraffin waxes in the lignite and brown coal oils.

The similarity of these oils is, to say the least of it, very striking. Add to this that the distillation curves are practically identical and very closely approach that of Pennsylvania crude oil, topped to 200°C. similarly to the coal oils. The justification should be apparent. See Fig. 3.

The curves marked "P. O." are Pennsylvania oil curves, while curves I, II and III are relatively oils from coking, medium coking and non-coking coals ("L & N" Process).

In the June numbers of the Gas Journal and the Iron and Coal Trades Review this year a full account of the above is published.

We have found that by the standard Engler fractionating method

TABLE VII

Engler Fraction Condensor Oil	% by weight on anhydrous crude
0 – 200°C.	2 – 4%
200 – 250°C.	14 – 16%
250 – 300°C.	16 – 18%
300 – 350°C.	16 – 18%
350 – 400°C.	25 – 30%
and above 400°C.	
Pitch coke.	16 – 20%
Losses to 420°C max.	2 – 4%

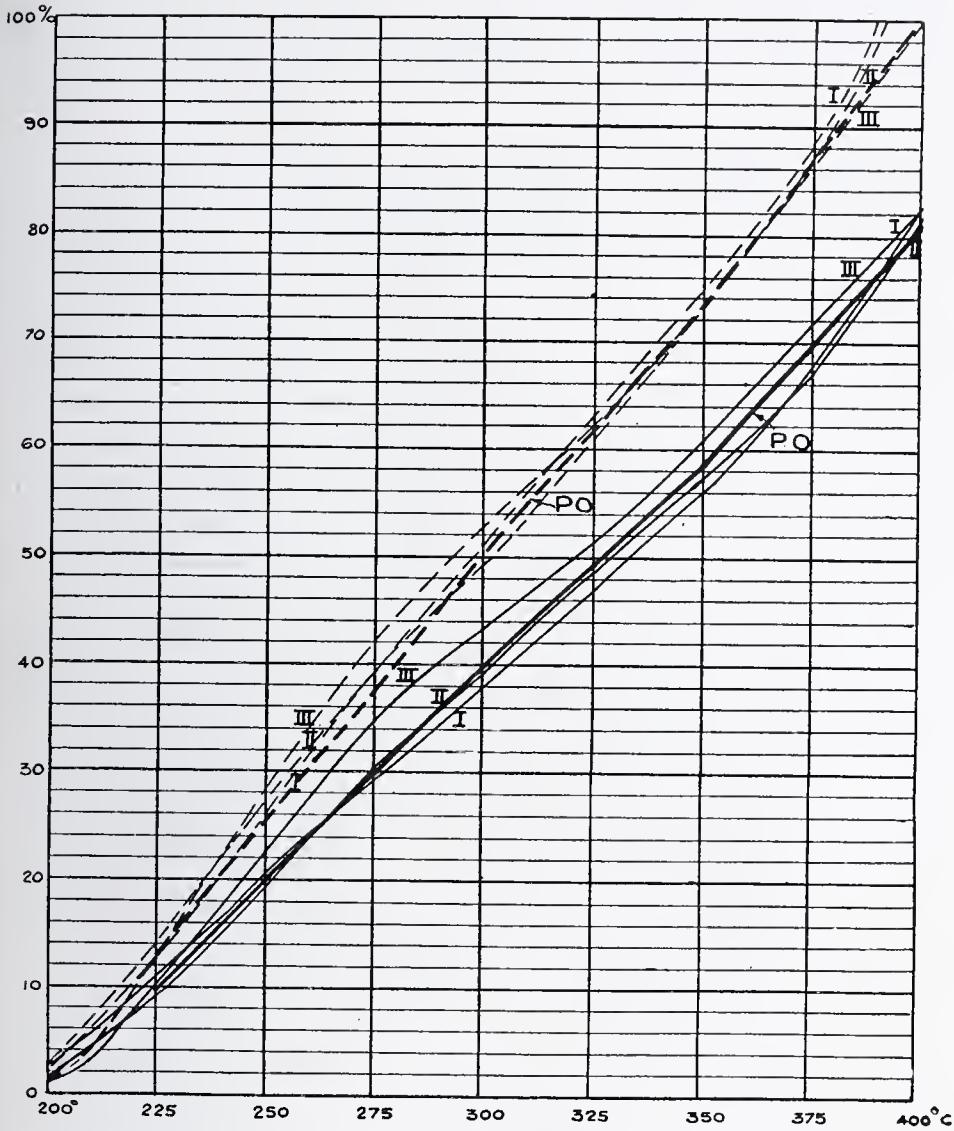


FIG. 3. DISTILLATION TESTS OF LIGHT OILS FROM BITUMINOUS COALS
"L. AND N." Process (Internal Heat)

all our primary crude oils obtained by large scale tests from the great variety of coals with which we have dealt fall within the narrow limits specified in Table VII.

The specific gravity of the crude oils D^{20} varies within the following limits, 1.045 to 1.060, irrespective of the kind or origin of bituminous black coal.

The higher boiling fractions are extraordinarily resistive to high temperatures as the following will show:

The unpurified fraction from 350-360 to 400-420°C. will stand being heated for four hours at 348°C.=660°F. without losing more than 1.3% by weight. There was no trace of free carbon being formed.

Table VIII indicates what may be obtained from the average oil produced from 1 ton of bituminous coking coal by distillation by means of the sensible heat of gas in a rotary internally heated "L & N" Retort, excluding the light spirit from scrubbing the gas.

TABLE VIII

100 P. Ct.	By Distillation and Refining	Lbs.	Gallons	Total Gallons
3.8	Light burning oil.	8	=0.925	....
9.5	Diesel oil (neutral).	20	=2.190	....
	Total neutral burning oil.			3.115
9.1	Light lubricating oil.	19.1	=1.890	....
10.3	Heavy lubricating oil.	21.6	=2.020	....
	Total refined lubricating oil.			3.91
1.4	Paraffin wax, purified.	3	....	0.33
15.5	Higher phenols and cresols, boiling 200° to 300°C. Highly disinfectant R.W.=15.	32.5	=3.13	....
21.5	Phenols above 300°C., R.W.=3.	45.2	4.35	....
	Total acid oils.			7.48
13.1	Pitch coke.	27.5		
5.2	Distillation losses.	....	....	....
10.6	Refining losses by using 10 p. ct. sulphuric acid, concentrated.			
100	Saleable refined oils recovered.	....	....	14.835

The total quantity of saleable oil will be found to vary between 74 to 78% of the total anhydrous crude oil, which we claim is more than can be produced by any other distillation or carbonisnig process to our knowledge.

The heavy lubricating fraction boiling above 360°C. we have not been able to locate in any other coal oil except our own.

Carefully conducted tests by independent authorities of the highest standing have conclusively proved that the lubricating oils obtainable from coals by the correct method are certainly as good as those obtained from well oils.

The above few remarks about oils from coals must suffice, but here is an unlimited field for pioneer work of the highest scientific interest, and where the time and money spent on research will be amply repaid.

(c) *Gas*

When employing externally heated retorts for low temperature treatment of coal, a large volume of gas has always been regarded as a sure sign that the oils have been decomposed. Under the above conditions, the assumptions are correct. A widely different aspect is provided by correctly applied internal counterflow heating; whatever temperature the coal, or rather solid residue, is subjected to after the oils have been set free cannot possibly interfere with the latter. All that happens is that the volatile matters left in the residue, after expelling the oils, are given off as permanent gases. Fig. 4 represents an actual temperature curve in our test retort, and indicates the predominant happenings at the various stages. Smaller volumes of gas are continuously given off during the oil stage, as well as the formation of water of constitution. Nevertheless, one can say that the gas evolution takes place in two distinct stages.

The first stage is synonymous with the oil stage, and the gas is characterised by a high percentage of methane and a low percentage of hydrogen.

The second stage occurs after the oils are expelled, and the gas is now rich in hydrogen and relatively poor in methane. Compare the figures in Table IX. "Low temperature gas from coal 'with' gas from semi-coke."

Further, the gas volume obtained in second stage is generally double that obtained in the first stage.

When the two gases are mixed together the volumes and relative percentages of components are those shown in Table X.

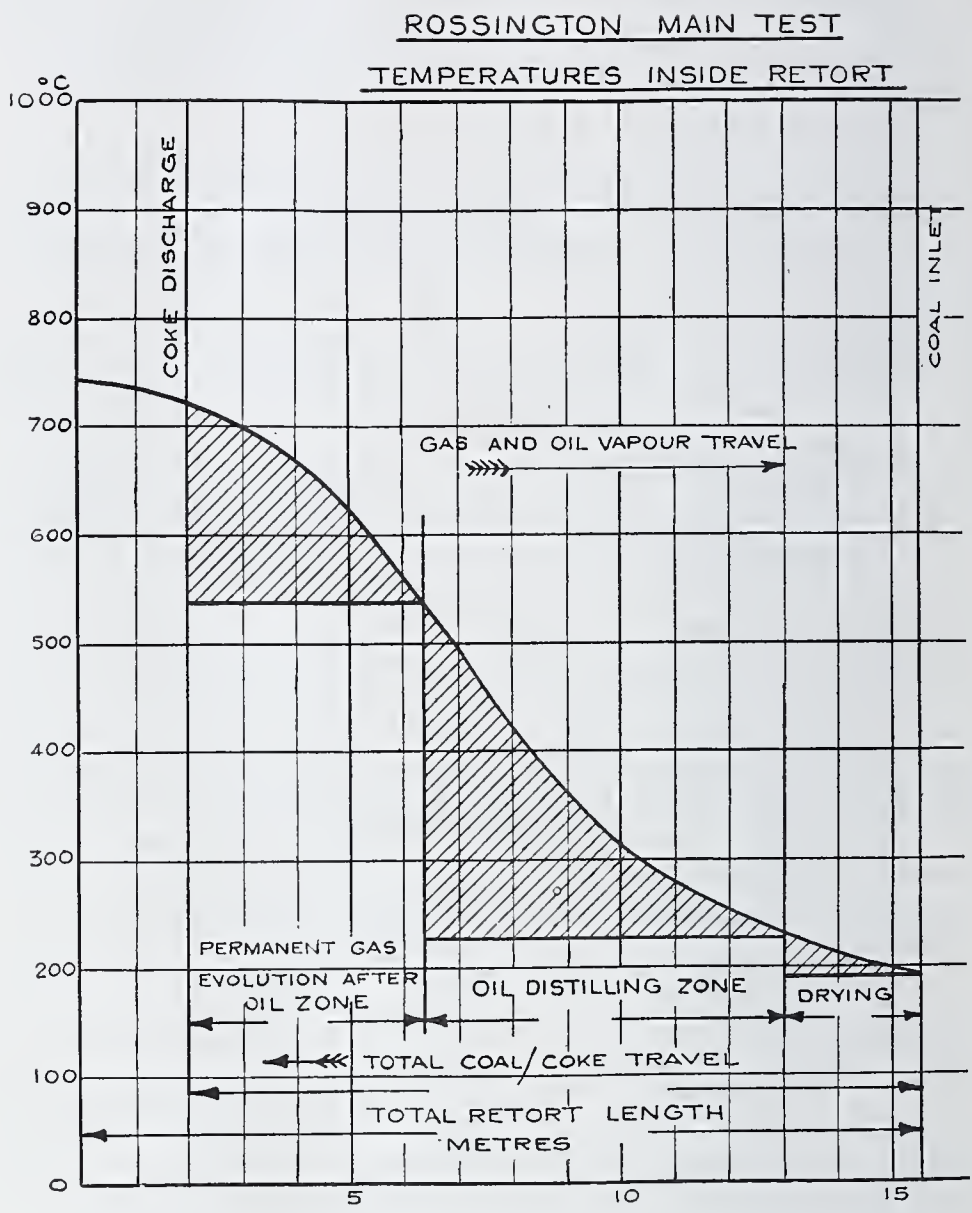

ROSSINGTON MAIN TEST
TEMPERATURES INSIDE RETORT
°C
1000
900
800
700
600
500
400
300
200
100
0
COKE DISCHARGE
COAL INLET
GAS AND OIL VAPOUR TRAVEL
PERMANENT GAS
EVOLUTION AFTER
OIL ZONE
OIL DISTILLING ZONE
DRYING
TOTAL COAL/COKE TRAVEL
TOTAL RETORT LENGTH
METRES
5
10
15

FIG. 4

TABLE IX.

Coal I is a Scottish non-coking coal.
Coal II is a coal from the Doncaster district (semi-coking).
Coal III is a coal from the Barnsley district (coking).

Gas Analysis	Coal I		Coal II		Coal III	
	L. T. Gas from Coal	Gas from Semi-Coke	L. T. Gas from Coal	Gas from Semi-Coke	L. T. Gas from Coal	Gas from Semi-Coke
	P. Ct.	P. Ct.	P. Ct.	P. Ct.	P. Ct.	P. Ct.
CO_2 — H_2S	12.0	7.2	9.4	3.7	5.2	4.5
CmHn	3.2	...	0.4	...	2.0	...
O_2	0.6	0.2	0.4	1.3	0.8	0.5
CO	9.4	16.3	8.0	11.3	8.4	15.2
H_2	15.6	48.5	22.5	64.3	26.4	59.8
CH_4	49.6	23.4	55.0	15.0	47.2	16.0
C_2H_6	6.4	...	1.6	...	4.2	...
N_2 — Loss	3.2	4.4	2.7	4.5	5.8	4.0
Cal. Val. B.T.U. per c. ft.	730	436	675	392	675	394
Volume per ton of coal.	2000	5500	2200	4000	3300	4800
DistillingTemp.°C.	550	900	550	900	580	900

TABLE X.

Gas Analysis	Coal I	Coal II	Coal III
	P. Ct.	P. Ct.	P. Ct.
CO_2 — H_2S	8.53	5.78	4.87
CmHm	0.82	0.14	0.81
O_2	0.30	0.97	0.62
CO	14.46	10.10	12.46
H_2	39.76	49.30	46.10
CH_4	30.35	29.25	28.70
C_2H_6	1.70	0.57	1.71
N_2 — Loss.	4.07	3.89	4.73
Calorific Value, B.T.U. per c. ft.	515	495	507
Total volume of mixed gas, dry coal.	8350 c. ft.	7900 c. ft.	8450 c. ft.
Specific gravity, air = 1	0.535	0.440	0.465
Weight per m^3, 0°.760 mm.	0.6931 kg.	0.5683 kg.	0.6024 kg.
Weight per c. ft.	0.0406 lb.	0.0362 lb.	0.03825 lb.
P. ct. inerts in gas.	12.9	10.64	10.22
Therms per ton of dry coal.	43	39	43
Oil obtained, gallons per ton	21	21	17.5

We have found and proved, by numerous tests, that the combustibility and reactivity of the solid residue is not in any way

impaired by the removal of the very largest part of the volatile matters in same. It is, therefore, of economic importance to recover, as far as possible, the far more valuable gas heat units since their sale value is nearly five to eight times that of those in the raw coal (see Tables I & II).

This we can do with impunity by simply raising the temperature of solid residue to any degree we like, round 850-900°C. after the oil stage. The percentage of volatile matters left in the solid residue will not now be more than 2-3%.

This secondary treatment—I call it the secondary treatment although it takes place in the same retort, and the coal continuously passes progressively from one stage to another in its course through the retort—opens out the possibilities of handling the coal at the pit, distil it, recover the valuable primary oils and the largest possible quantity of gas and transmit same by long distance piping to where it is wanted (See "Long Distance Transmission of Town Gas," The Gas Journal, February 10, 1926). Very carefully carried out calculations indicate that the cost of transmitting 100,000 B.t.u. of the gas of which particulars are given in Table X, over a distance of 75 miles, will cost 0.7916 penny or 1.616 cent.

This figure includes pumping and compression costs (starting pressure 11 atmospheres absolute), maintenance and repairs of pipe lines and compression station, inspection, unavoidable losses (5% on total quantity transmitted), etc., and is based on the transmission of round 50,000,000 cubic feet per twenty-four hours.

The subject of long distance gas transmission is too well known for me to enlarge upon on this occasion.

There is one more aspect of our method of treating coal to which I should like to refer briefly, I mean the transforming of the fines and breeze from the solid coal distillation residue into producer or water gas.

We could just as well start with the small raw coal, only in the first case a gas entirely free from tar vapors is produced. This is of great importance for large gas engines, although the latter gas will give a more suitable luminous flame for general open hearth furnace work.

The difficulty of dealing with smalls in an ordinary gas producer needs no comment. Everybody knows that. Bourgoud at-

tempted to deal with such material in a powdered form, but in uniflow. His work is also common knowledge. We approached the matter from different angle. We employ the counter-current principle.

In an ordinary gas producer only 70% or round this figure is recovered in the gas in the form of latent heat; the balance, or 30%, is accounted for as sensible heat in the gas, radiation losses, convection losses, unburnt carbon, soot, etc.

We take 25 to 30% of the coal to be gasified, powder this, and fire it as powdered fuel with the necessary air, plus a slight surplus to assure complete combustion in a furnace built like a rotary cement kiln. The other 70% enters the kiln at the opposite end, as the cement slurry would otherwise. The combustion of the 30% of coal provides the requisite reaction temperature and CO_2 volume. We now have the interaction between CO_2 and carbon at very high temperatures, and consequently reduction of CO_2. Steam may also be admitted so as to obtain the H_2O—carbon reaction. Since the operations are conducted in strict counterflow the carbon will continuously meet higher and higher temperatures until completely consumed, the ash being removed as clinker at the lower and hottest end of the kiln. The possibility of direct ore reducing and smelting will be studied later on.

We have now erected and commenced large scale experiments along the new gas producing lines, and I hope to be able to supply interesting facts and figures at the time of reading this paper.

As far as we can see at present, the practical possibilities exist of dealing, in a single gas producer on these lines, with up to 150-200 tons of fuel per day.

Fig. 1, No. 7, gives a diagram of the producer.

It will be clear at once that there is nothing novel in the designing or operating of such rotary furnaces, retorts or producers. We know exactly from cement kiln practice on a very large scale how these pieces of machinery operate, what the wear and tear are. The only thing new is the application of old, well established apparata and knowledge to cope with new principles and problems in coal

which present themselves during the progress of economic evolution and, of course, attempting to deal with the matter on as sound a scientific foundation as within present day knowledge.

Conclusions

A brief survey of the new possibilities presented by distilling bituminous coals and lignites in bulk in rotary internally heated retorts on the "L & N" principle has been attempted.

As far as possible, at the present stage of knowledge of coal, it has been indicated that a new series of products, solid, liquid and gaseous, may be obtained under the above conditions.

These products possess properties which render them particularly valuable from an economic point of view.

It has been indicated that the combustibility, etc., of the solid residue in lump or powdered form is not so much dependent upon the volatile matter contents as upon the structure and the necessity of preventing the formation of a graphitic film by counter-current distillation.

The remarkable similarity between the Fischer analyses of the primary oils produced by the "L & N" principle from a wide range of coal seems to prove that the neutral oils are for all practical purposes identical.

It has been indicated that a large volume of permanent gas, equal in every respect to town gas, may be produced from bituminous coal by the "L & N" distillation method without altering the primary nature of the oily products, or interfering with the easy ignitability and combustibility of the solid residue, in solid or powdered form.

It has been indicated that the "L & N" principle of distillation lends itself to a great number of combinations, whereby any industrial demand for fuel in any shape or form may be satisfied economically.

Evidence has been given of the similarity of products obtained by the "L & N" principle, both as far as quantity as well as chemical properties are concerned, irrespective of the size or throughput of the retort.

Capital and operating costs are stated on the basis of large single units.

The lines along which the technical staff of the "L & N" Process is conducting research have been indicated.

This research has further proved the commercial value of the resultant products from coal distillation on the "L & N" principle.

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Harald Nielsen's Evidence.

DISCUSSION

ERIC SINKINSON.* I should like to ask Dr. Parr whether his curves for the rate of oxidation of coal shown on the screen do not explain to some extent why coal will not melt or become pasty after it has been held at some definite temperature just below the melting point of the coal. Is it because the liquescent substance in coal has an avidity for oxygen and the resulting oxygenated compound formed afterwards decomposes without going through a pasty stage?

My attention was called to an article in "Fuel," June, 1926, by E. Audibert, on the "Transient Fusion of Coal," in which he indicates that thermal decomposition of a coal in an atmosphere free of oxygen will take place at a lower temperature than the fusing point if the temperature be held for some time below the said fusing point and this is an inherent property of the organic substances composing the coal complex.

Could not Audibert's results be explained more simply from your oxidation curves for coal by assuming that during the lengthy heating below the fusing point, oxygen is somehow taken up by the liquescent constituent of the coal, thus altering its behavior?

S. W. PARR. I think there are two problems involved.

If we permit of oxidation as the temperature rises we change our constituents in a way to raise materially the melting point of the coal. There is no conflict in our ideas along that line, we have many experiments showing that a slight ascent of the melting point accompanies oxidation until the pasty stage disappears entirely and there becomes no melting point at any temperature.

Now the work of Audibert is along quite different lines, and assuming there is no oxidation in his system, it is explained in my own mind at least in this way: In general each organic compound has a melting point, and at the melting point it begins to decompose a little. Suppose we hold it at the melting point until all decomposition at that

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temperature is complete, then bring it down and heat it up again. Its melting point will now be a little higher. Upon heating again, a little more decomposition takes place, and the melting point is again higher, that is, each stage of decomposition results in a product having a little higher melting point until it reaches a composition which has no melting point at all. I think the work of Audibert is not inconsistent with this theory. A change in the melting point may be due to two things. First, oxidation has its own method of behavior, and second, the slight progression of decomposition which accompanies the heat of liquefaction results in a succession of altered compounds having higher and higher melting points.

E. A. MUNYAN.* Mr. Nielsen spoke of using powdered fuel on sea-going vessels, in a Scotch marine boiler. I would like to know the moisture left in the coal, after it is dried, which is used on board these ships. The next thing, assuming it is used, how the different coals are arranged for at various ports of the world. If you get at one port a certain type of coal and at another port a different type of coal I would like to know how that could be handled in a marine boiler.

HARALD NIELSEN. At present we are simply going north a short way, at home ports. As far as western ports are concerned, it really doesn't matter, because we are going to use primary treating there of about 250° C. or something like that. The coal will contain moisture something like at the present. It does not look much at the present time, but we can do it when the coals are to be had at home ports, also at coaling stations. It will take years to do it, a long time, but we will do it eventually.

LESLIE R. THOMSON.* Coming from the land of the Eskimo, a paper such as Mr. McIntire's is to me very interesting. The importation of anthracite fuel into Canada runs in the neighborhood of 4½ million tons. Through the last few years some definite effort has been made towards substitution of one kind or another, but the substitutions haven't reached a volume larger than three-quarter million tons. This includes importations to supply the demand of by-product coke. Mr. McIntire's paper places primary emphasis on anthracite substitute, hence it is extremely interesting to Canada.

I was interested too, to observe that Mr. McIntire emphasized that he had taken the jump in his work from the desultory work of scale operations into something definitely commercial. A process that has treated 25,000 tons is beyond the development state, and those who go through the development process and have attempted to pass to the full scale operation are perhaps able to realize better the full magnitude of the accomplishments that Mr. McIntire and his associates have made.

Another point is the very interesting figures submitted by Mr.

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*Consulting Engineer, Montreal, Canada.

McIntire in his economy of heating surface. He gave the figures of 14½ pounds of coal per hour per square foot of heating surface and compared that with 2 to 3 pounds of the high temperature coke oven. Doesn't this indicate that such a process as he is working on, holds within itself the germ of true economy? In other words, a great many things can be done, but the point is, will they pay in an open commercial form.

Mr. McIntire emphasized his approach to the subject as an engineering one. He remarked several times during his paper that he thought of his retort as a machine. This gives great encouragement to those of us who are engineers and are also approaching similar problems.

DAVID WHITE.* The description of the researches and the results that are reached by the investigators who have spoken will be of far reaching significance to geologists, as well as to technologists and the manufacturers of coal products.

The experiments in the oxidation of coals constitute a subject in which I have been interested for many years, though not a chemist. It is becoming more and more apparent that some of the organic compounds in the plant material forming a coal, are exceedingly unstable. It would be interesting to know the results of oxidation tests of coals of different kinds: (1) at different temperatures; (2) at different pressures, and (3) after exposure to various gases. I hope such tests have been or will be made.

It has been noted by several speakers, particularly Professor Parr and Mr. Nielsen, that the oil and gas generation mostly takes place at an early stage (around 450° C.), which precedes the stages of marked carbonization. I should like to state that Miss Stadnichenko, who is studying oil shales and some coals by means of a micro-furnace, reaches results in general close agreement with those described by Professor Parr. It may be interesting to note, also, that in carbonaceous deposits of the rank, i.e., the stage of carbonization, of the Illinois coals, Miss Stadnichenko finds the different optically visible fossil constituents to react at different temperatures, an observation which shows differences in the composition of these constituents as they are now found at that stage of natural geological carbonization. Further, she has observed that some of the constituents of the coal appear to exhibit several different temperatures of chemical change as the temperature increases.

There is possibly analogy, and there should be, between the devolitilization or carbonization of coals in the furnace on the one hand, and in the ground on the other. The observation of the distribution of petroleum indicates that, in general, heavy oils of low rank are found in formations in which the carbonaceous deposits, including

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coals, are of the lignitic rank or barely of the sub-bituminous or next higher rank, the oils in formations associated with coals of the higher sub-bituminous ranks, being, on the whole, of higher order, those of moderate bituminous rank being generally still lighter and more fully saturated, while the lightest oils comprising largest proportions of saturated hydrocarbons occur in areas where the carbonization of the organic matter corresponds to a fixed carbon approaching 59% to 61% ash-and moisture-free basis. This stage of the carbonization of coals approximately marks the extinction of oil deposits in the different regions. It falls somewhat short of the development of good coking quality by old processes, which is marked by a percentage of 65% to 68% fixed carbon in pure coal, as, for example, in the Connellsville Basin. The generation of the petrolic distillates at or below 450° C. in the retort or the micro-furnace, may tentatively be conceived as falling below the stage in natural carbonization marked by a fixed carbon of 58% in the ash-and moisture-free coal.

May we not hope that in the progress of these investigations we may soon arrive at the discovery of the chemical changes which actually take place in the generation of these oils and in the concomitant carbonization of the coals? When this fundamentally important chemistry is known we will have made great progress in our understanding of the chemistry of the generation of the natural petroleums and gases under ground; our knowledge of the processes of natural carbonization or the metamorphism—for such it is—of the organic sediments buried in the strata, will be greatly advanced, though we must remember that in the geological processes time and pressure compensate to an unknown degree for the high temperatures used by the investigator in the laboratory. At least the processes must be largely similar.

FRANK M. GENTRY.* In the development of his process for the low temperature carbonization of coal, Prof. Parr seems to have had a very specific problem in mind, the production of a domestic grade smokeless fuel from Illinois coal. Because of his utilization to a great extent of the exothermic reactions of the charge during carbonization to effect uniform heating, this process is particularly adapted to such coals as are strongly exothermic in their behavior. The very excellent work done by the U. S. Bureau of Mines at its Pittsburgh Experiment Station under the direction of Davis on the heat of carbonization of coal has shown that most carbonaceous materials reach maximum liberation of heat between 400° C. and 600° C., the energy liberated varying from about 175 cal. per gram at 560° C. in the case of sawdust to about 7 cal. per gram at 460° C. in the case of anthracite. Illinois coal liberated a maximum on the average of about 32 cal. per gram at 500° C., the exothermic reaction beginning at about 340° C., and continuing well be-

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yond 700° C. Prof. Parr removes his charge from the primary preheating retort at about 300° C., and carbonizes it in the secondary retort up to about 750° C. It is very easy to see how closely he treats his charge within the limits of exothermic reaction. Sufficient heat is liberated to raise the temperature of the coal between 100° C. and 150° C., depending on the specific heat of the coke at that stage of its heating.

One advantage not generally set forth in behalf of a two stage process such as that used by Prof. Parr and others, notably, Illingworth, is that separate removal of the moisture greatly reduces trouble from emulsification of the tar, thus reducing the difficulties of its treatment. Furthermore, elimination of carbon dioxide evolved in the early stages of distillation increases the quality of the gas and reduces to a certain extent the work on the auxiliary apparatus.

Regarding the semi-coke as the principal product of low temperature carbonization, I have always liked to distinguish between three cases in order to avoid confusion, the production of a boiler fuel, the production of a domestic and industrial smokeless fuel and the production of an anthracite substitute. It seems to me that these three cases are quite clearly defined and in considering balance sheets of any process it should be borne constantly in mind to what class it belongs. The McIntire three stage process falls among those endeavoring to produce a semi-coke comparable to anthracite from a cheaper grade of coal with recovery of by-products.

To produce an artificial anthracite certainly requires the application of pressure to the semi-coke at some stage in the processing. In the McIntire process this takes the form of briquetting between primary and secondary carbonization. Other experimenters have adopted the method of briquetting, some before carbonization and some after carbonization. As an example of briquetting before carbonization may be cited the Pure Coal Briquet Process, developed by Sutcliffe & Evans. In this process the coal is briquetted without binder under a pressure of 10 tons per square inch and then carbonized in an internally heated retort. It is understood that the Fuel Research Board has also found it advantageous to briquet before carbonization in order to permit a free passage of gas through the retort. As an example of briquetting after carbonization, may be cited most any of the rotary retort processes where it is necessary to briquet the comparatively large amount of breeze before it can be marketed. Compression during carbonization is effected in the Bussey Process by the superincumbent charge above the plastic layer and in some processes, such as in one of the Coalite retorts, compression is effected by actual swelling of the charge, collap-

sible plates being provided to permit removal of the semi-coke. A number of attempts have been made to use pistons in the retort, as in the case of Parr's early work and Summers' retort.

Although it may be said that the application of pressure to the semi-coke, either through briquetting or otherwise, increases greatly the cost of processing, at the same time I think it will be found, if an income account is set up for a process manufacturing a smokeless fuel and for a process manufacturing an anthracite substitute, the net earnings will be in favor of the additional processing at the present time. Anthracite substitutes can be sold considerably below anthracite with a substantial profit, but a smokeless fuel cannot sell much below the raw soft coal, despite its advantages, and realize sufficient return on the investment. After all is said and done, in a new industry, where the advantages of a new fuel are not tremendously self-evident, the new fuel cannot command a price greater than the established competitive fuel.

The railroads of this country consumed about 26% of the entire soft coal used in the United States, and incidentally produce a large amount of smoke in the vicinity of our cities. It seems to me that semi-coke briquets are an ideal locomotive smokeless fuel and I believe tests confirm this opinion. It would be a tremendous step in the purification of the atmosphere, if railroads could be induced to adopt smokeless fuel by an actual large scale demonstration that it was more efficient than coal and no more expensive. This is an end towards which to strive.

Low temperature carbonization by internal heating, such as described by Nielsen, has certain definite advantages. In the first place, there is a relatively high efficiency of heat transfer to the charge, as compared with external heating, on account of the low thermal conductivity of coal, thus lowering the thermal loss attributed to carbonization. In cases where large amounts of gas can be used, it is advantageous to use the sensible heat of producer or water gas to effect carbonization, but where such large amounts of gas cannot be disposed of, internal heating can be conveniently performed by re-circulating a portion of the withdrawn gas in a closed circuit through a superheater.

Another advantage of internal heating by water gas, producer gas or scrubbed low temperature gas, is that it lowers the partial pressure of the volatile products, so that the effective pressure of distillation is reduced. This, to a large measure, prevents cracking. Cracking is at the same time further reduced by the sweeping action of the heating medium which carries the evolved gases to cooler regions in a countercurrent fashion as soon as they are formed. This conserves the primary character of low temperature tar.

Sometime ago I had occasion to investigate the cost of by-product recovery for certain internally heated low temperature processes which

used the sensible heat of producer gas as the heating medium. The quantity of gases handled necessitated an expensive by-product equipment, for the capacity of the apparatus must be increased many fold over that required by externally heated systems. Also the work on the scrubbers and condensers is greatly increased in proportion to the quantities recovered. It is a question in my mind whether in such cases it is at all profitable to recover the ammonia in view of its comparatively small yield and the cost of the necessary equipment.

THE McEWEN-RUNGE PROCESS FOR THE LOW TEMPERATURE DISTILLATION OF COAL

By Dr. Walter Runge
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McEwen's Early Work

By the year 1919 many attempts had been made to give practical and commercial application to a method of treating bituminous coals at a temperature which would secure the maximum possible yield of liquid product and, at the same time, produce a residual solid fuel which would have properties making it more attractive to the consumer than the raw fuel normally available.

In this attempt great difficulties were encountered and it appeared possible, by carefully reviewing all the efforts which had been made and the results which attended those efforts, to establish certain broad principles which would govern the solution of the problem and the strict observance of which would lead to success.

The numerous difficulties, apart from mechanical ones, which beset those engaged on the work may be classified under two main heads and may be briefly stated as follows:

One difficulty was the necessity of heating the fuel to the desired low temperature without overheating any part of it and without overheating the products of distillation. This necessitated a very low temperature difference between the heating medium and the material to be heated, with the result that the rate of heat transmission was extremely slow, giving an extremely low output from the retorts and a consequent high capital charge and low thermal efficiency owing to high radiation losses.

The other difficulty was the tendency to produce a solid residue of so light and friable a character as to make it entirely unsuitable for transport or, in other words, unsuitable for commercial use.

At this time, those engaged in the field of power generation were very much attracted by the possible success which promised to attend renewed efforts to develop the combustion of powdered fuel for power generation purposes. It was clear that a very powerful effort was being made, and

that this effort was receiving very widespread support. McEwen was one of those who foresaw the possibility of an enormous development in the combustion of powdered fuel, which led him to realize that if such development actually occurred, the problem of carbonizing fuel at low temperatures would be approached from an entirely different standpoint for the reason that, assuming a demand for a powdered semi-coke, the main difficulties which attended the efforts to solve the low temperature carbonization problem could be largely eliminated. McEwen, therefore, conceived the idea of first pulverizing coal in precisely the same way as would be done preparatory to combustion, and to heat this powdered coal while in suspension. The enormous surface which would be presented to the heating medium by powdered coal in suspension would permit of a greater rate of heat transference, even with an extremely low temperature difference, as compared with the extended time required in processes hitherto tested. Theoretically, it was possible to reduce the time required for heat transference from a period of hours to seconds.

Again, assuming that the results of carbonization in suspension would be to produce a powdered semi-coke and that this powdered semi-coke could be transferred to the powdered fuel burners of a furnace, its friability is no disadvantage; on the contrary, it would be an aid to intensely rapid combustion.

Following the conception of this possible line of development, it became necessary to conduct such practical investigation as would disclose the prospects which might be expected to attend final commercial application.

Following preliminary work in a laboratory, which consisted in causing small quantities of pulverized coal to fall through a vertical tube up which heated gases were rising, and which gave encouraging results, an experimental plant was erected in London for trial purposes. At this stage it was conceived that the practical and commercial application of the process might take the form of a closed circuit through which hot gas would be circulated and into which powdered coal could be fed, caused to travel round the circuit, and be removed by means of a cyclone separator which would form part of that circuit. It was further realized that the temperature could be maintained by burning some portion of the permanent gas within the circuit, so that the products of combustion would mix with the circulating gas and maintain their temperature. By using a special burner it was found possible to insure that combus-

tion was restricted to the volume of flame, and as no free oxygen was admitted to the circuit no danger arose from having a naked flame in a circuit through which powdered coal and combustible gas were circulating.

The plant was put into operation in November, 1919, and many minor difficulties were encountered. The feeding of the powdered coal, which was quite cold, to the circuit which contained some products of combustion, led to the condensation of water on the feeder and the incoming coal, which prevented a continuous or satisfactory feed. This difficulty, of course, was readily overcome by heating the feeder and maintaining it at a temperature above that at which moisture will condense.

The plant consisted of a circuit of cast iron pipes six inches in diameter, the length of the circuit being approximately seventy feet, and it was assumed that with a velocity of gas within the circuit of forty feet a second, the coal in its passage through the circuit would be under treatment for one and three-quarter seconds.

It was found difficult at first to maintain the whole circuit at the desired temperature, for in spite of the use of high grade lagging on the pipes loss by radiation was found to be largely in excess of that which was anticipated.

A supply of pulverized fuel was obtained from a cement works, which coal contained twenty-three per cent. of volatile matter and was a coking coal, and this was fed into the circuit. For the reason stated above, the average temperature of the circuit was low, being not above six hundred degrees Fahrenheit, and it was found that the coal passed through the circuit satisfactorily and could readily be continuously removed from the cyclone separator.

An examination of the fuel discharged from the cyclone showed that its appearance had changed materially and it had all qualities of a semi-coke. It was in the form of a very fine powder which had no coking property left; but the carbonization, owing to the low temperature, was by no means complete, the volatile matter having been reduced only from twenty-three to nineteen per cent.

Trials were repeated, using a different fuel obtained from another cement works, but which contained thirty-four per cent. of volatile matter, and similar results were obtained. The dust discharged from the cyclone was in the form of a very fine powder, but carbonization had only proceeded to about the same degree as with the first coal used,

It was realized that the next stage would be to increase the temperature of the circuit in order to reduce the percentage of volatile matter in the residual coke; but the work already accomplished had shown that a coking coal, which must in some stage of heating become plastic, did not adhere to the walls of the circuit, nor did the particles adhere to each other, but readily passed through the circuit to be discharged in the form of a powder, quite suitable for combustion in suspension.

A modification to the small combustion chamber and burners enabled the temperature of the circuit to be raised when it was found that, owing to the increased temperature and the consequent rarification of the gas in the circuit, a velocity of 2400 feet per minute was insufficient to keep the fuel in suspension. As the plant was erected a very large portion of the 70 feet of circuit was horizontal and, for some time, efforts were concentrated on determining the minimum velocity of gas necessary at the desired temperature to secure carbonization in order to maintain the material in suspension. An increase in the velocity naturally reduced the time available for treatment and, with a velocity of 4800 feet per minute, the time for treatment of a 70-foot circuit was only three-fourths of a second. Since it was found that a velocity in excess of 4800 feet per minute was necessary to insure suspension in gas at the required temperature, it became apparent that the use of a closed circuit was not the most satisfactory way of giving practical application to the method of carbonizing dust fuel in suspension. Thus it was clear that if powdered coal was allowed to fall by gravity through a vertical tower against an uprising current of hot gas the time of treatment for a given length of travel would be enormously increased. Rough calculations indicated that a vertical retort 40 to 50 feet in height would be more effective than a closed circuit as much as 150 feet in length.

The results of this first practical application and experimental plant were:

1. To indicate that for further development it would be desirable to revert to the form of a vertical tower.
2. That it would be necessary to preheat the coal to a temperature above that at which condensation would take place prior to its admission into the carbonizing chamber.
3. That the coking property of a coking coal was destroyed by being heated in an inert atmosphere with a comparatively small reduction in the percentage of volatile matter.

4. That with the coals tested, the carbonization of fuel in suspension resulted in the production of a powdered residue.

THE DEVELOPMENT UNIT

After the work which McEwen had done in London, it was deemed advisable to continue the development work in the United States where pulverized coal could be more readily obtained, and where the co-operation of a plant using pulverized coal could be had. The unit that was constructed at the Lakeside plant of The Milwaukee Electric Railway & Light Company was twelve inches in diameter and approximately thirty feet high, with a flared top whose greatest diameter was three feet, well insulated on the outside, and equipped with a single feeder, two gas offtakes at the top and a hand-operated coke discharge at the bottom. There was no gas available at the Lakeside plant at this time, and it was therefore necessary to depend upon the hot products of combustion from oil burners for the carbonization. There was therefore built at a point in close proximity to the retort a brick furnace into which was projected the flame of the oil burner. The hot products from this combustion chamber were then led directly into the retort, meeting the descending coal. This unit was not equipped with any by-product apparatus, and all the gaseous products from the carbonization were vented directly to the atmosphere.

The first series of tests that was made with this unit indicated—contrary to McEwen's earlier results—that it would not be possible to handle a strongly coking coal in a single stage, inasmuch as the semi-coke, while at times extremely fine, was at other times coarse and with a small percentage of lumps. After the appearance of this lumpy coke a number of tests were made whereby the coal was given a preliminary heat treatment and this treated coal, after having been removed from the retort, was stored until such a time as it could be re-run and carbonized. This coal which had received the preliminary heat treatment at temperatures between 500° and 600° F. displayed little or no coking properties, and as a result, when it was put through the process again to be carbonized at higher temperatures the semi-coke was exceedingly fine in structure, showing as much as 40% passing a 200-mesh screen, compared with 60% for the original coal.

Many tests of various kinds were made, all tending to establish three points:

1. That the height of the retort was great enough to allow the carbonization to be completed.
2. That, with strongly coking coals, the coking properties of the coal were destroyed by pretreating the coal at temperatures between 500° and 600° F., and
3. That with proper control, the loss of dust being carried away by the gases was not a serious one.

All of these points were well established in the development unit, which formed the basis for the design of the commercial unit now erected at Milwaukee.

General Description of the Milwaukee Unit

To give some idea as to the size of this carbonizing unit it might be well to state that the building within which it is housed is 140 feet high, 40 feet long, and 25 feet wide, with a lean-to for sheltering the exhauster and pumps 32 feet high and 25 feet square. The unit consists of two retorts identical in construction, one superimposed on the other and each approximately 40 feet in height, and 6 feet 9 inches inside diameter. The retorts are cylindrical in shape except that at a point 11 feet from the top each retort flares upwardly and outwardly, so that the inside diameter of the top of each retort is approximately 13 feet. These retorts consist of steel shells one-fourth of an inch thick with two joints in each shell where the vertical sections of the shell overlap each other for a distance of three inches, thus permitting the shell to expand or contract without materially affecting its tightness. The insulation of the retorts is taken care of by 4½ inches of insulating material and 4½ inches of firebrick, which forms the inside lining of the shells.

At the very top of the building is a bin for the storage of the pulverized coal, the coal being pumped to this bin from an adjacent pulverizing house which forms part of the steam raising plant. This bin has a capacity of approximately 25 tons and is equipped with four feeders which conduct the coal from the bin into the retort by means of pipes which extend downwardly into the retort for a distance of about six feet. Each feeder is of the star wheel type having six pockets, and these are connected with variable speed motors so that each and every one may be run individually or collectively and at various speeds, permitting a minimum of one ton per

hour and a maximum feed of sixteen tons per hour. The upper or primary retort discharges into a small hopper having a capacity of five tons. This hopper is provided with four feeders and four feed pipes which not only conduct the coal to the secondary retort, but act as a seal to prevent the gas from the lower retort entering the upper retort.

One of the main features of this process, and one in which it differs from nearly all others, is its system of heating, which consists of introducing hot gases into the retorts to effect the pretreating and carbonization of the coal.

The method of heating is common to both retorts. Each retort is equipped with two combustion chambers that are connected tangentially to the bottom of the shells. These are cylindrical in shape, with an inside diameter of three feet nine inches and a length of six feet six inches, and are lined with thirteen and one-half inches of insulating material and fire brick. At the end of each combustion chamber a high pressure burner is installed. These burners operate with a gas pressure of one to nine pounds according to the quantity of gas that it is desired to burn, the air for combustion being inspirated. The hot gases from the combustion chambers enter at the bottom of the retorts, and as the gas outlet is at the top they rise counter-current to the descending coal.

The equipment for handling the by-products is standard, consisting of the usual exhausters, tar extractor, direct cooler, cooling coils, circulating and storage tanks, gas holder and pumps, and needs no further mention.

The plant as originally constructed contained a coke cooler which consisted of a sectional cast iron retainer whose dimensions are approximately nine feet square and ten feet high. This contained a large number of 1¾-inch tubes around which the hot coke was to pass, and through which it was proposed to pass the gas to be used in the process, thereby extracting a large part of the sensible heat of the coke. This arrangement was not satisfactory and the tubes have since been removed. It is felt, however, that the principle is correct, and a new construction is now being designed.

For the present, the hot coke is cooled by direct contact with steam; but this is only a temporary measure to permit continuous operation. The coke is discharged from the cooler into conveyors which conduct it to a transport pump, which forces it to the boiler house, situated at a distance of one hundred and fifty feet. The coke is not cooled to atmosphere temperature, but reaches the boiler house at a temperature of about 250° F.

All of the recording and indicating pyrometers, recording tachometers, CO_2 recorders, pressure indicators and recorders are placed in an instrument room located at a central point. In addition to this all the switches in connection with the feeders and coke conveyors are contained therein, and it is possible to regulate the feed of the coal from this remote point. The gas burned is regulated automatically and the control is also located in the instrument room. With this arrangement the entire plant, with the exception of the exhauster and pumps, can be supervised and operated by one man from a central location, thus greatly simplifying operation and control, and greatly reducing labor.

Operation

There have been a number of criticisms made of carbonizing by internal heating and some of these probably have been justified, on the basis of a single retort unit using hot products of combustion. The objections consist mainly in that, by this system of heating, the quantity of inert gas that enters the retort is so great that the gas produced by the process is of little value; and furthermore, that the concentration of the light oil from the coal in these gases is so low as to make it difficult, if not uneconomical, to recover. By operating with two retorts these objections are overcome, for it is possible to perform half of the work in the upper or primary unit by bringing the coal to approximately 500° F. without any appreciable loss in volatile content, while the gases from this preliminary treatment may be wasted to the atmosphere without any serious economic loss. Inasmuch as the coal enters the secondary retort at a temperature of approximately 500° F. the quantity of hot gases that are used for the carbonization—when compared with a single retort process—is practically cut in half, and it is therefore possible to obtain a gas of a satisfactory heating value and at the same time permit the recovery of the light oils. Another objection to internal heating has been the size of the auxiliary gas handling equipment, but by means of the dual retort system this approximates in size that which would be used in a by-product coke plant operating on the same tonnage.

It is probably well understood that it is not the object of this process to produce a domestic or lump form of fuel, but rather a fuel the size of whose particles permits it to be used with no, or at the most, with little additional preparation, in a pulverized coal burning plant. Were non-coking coals the only ones to be taken into consideration, the problem

would be a relatively simple one. When, however, a coking coal is carbonized in pulverized form while falling freely through a vertical retort against a rising current of hot gas the particles of coke produced are much larger than those of the original coal. For example, the raw coal may be pulverized to meet a common power-plant specification: 65% through 200 mesh and 100% through 20 mesh. The coke made directly from a coal of this fineness will be: 0% through 200 mesh and 70-100% through 5 mesh. Such a coke is difficult to pump and inefficient to burn in a boiler plant employing pulverized fuel.

This increase in particle size is due to the coking or binding property of the coal. During its descent through the retort each individual particle of coking coal passes momentarily through a plastic state. While in this condition it tends to cohere to any other coal particle, similarly plastic, with which it chances to come in contact. The natural result is that the coke reaching the bottom of the retort does not retain the fineness of the parent coal, but consists of a multitude of aggregates or clusters of tiny coke particles. This physical characteristic is clearly apparent to the naked eye.

Such coke is soft and easily crushed to powder between the fingers. When it is remembered that a coal particle carbonized in a gas stream "explodes" almost like pop-corn into a minute sphere filled with gas, it will be recognized at once that the grinding of so light and porous a material presents a negligible engineering problem. However, it is felt desirable to reduce to a minimum an operation of even this simplicity.

Untreated coal yields a brittle gray coke of the familiar metallic lustre. Coal with its coking property destroyed yields a soft, dull black powder, which for lack of a better term may be described as "char". Untreated coal tends to expand in volume in becoming coke. A char, on the other hand, occupies the same volume as the original coal. Between these two extremes of coke and char there can be produced carbon residues of widely varying coking strength.

The most familiar example of the partial or complete destruction of the coking property is the weathering of coal exposed to air. This phenomenon is probably due chiefly to the oxidation of some part of the coal substance. It is possible also that the moisture in the air supplements this effect. At all events, there is clear evidence that it is a surface reaction, working from the outside in. We can recognize, therefore, four principal

factors involved: the area of contact, the time of contact, the temperature, and the atmosphere.

In dealing with coal pulverized for steam raising the area of contact is, of course, the maximum that can be attained in practical technology. When 65% passes 200 mesh and 100% passes 20 mesh the ratio of surface to weight is about as favorable as can be desired. A cubic inch of coal of this fineness has over 100,000,000 times the surface of the same volume of solid material.

The area of contact is fixed by the pulverizing of the coal. The time of contact is largely determined by the design of apparatus employed. Temperature and atmosphere, however, are variables under the control of the operator. It is obviously advantageous to operate at the maximum temperatures possible without appreciable loss in volatile.

The last factor is the atmosphere to which the coal is exposed. Presumably higher concentrations of oxygen through mass action will favor the completeness of the reaction. Finally, the question of water vapor is a factor that may also play a part.

In determining the coking index of the raw and treated coal we have employed a modification of some of the other known methods and a description of it is not necessary at this time. It has been shown as a result of these tests that the coking index of the coal has consistently been 100 with that of the treated coal varying from 0 to 90, depending upon the conditions within the retort. The strength of the coke varies according to the temperature and atmosphere employed. With a temperature of 555° F. and an atmosphere that contains an excess of ½% oxygen, the coking index was 70, with a reduction in volatile of the coal from 34% to 30%. With a temperature of 580° F. and an atmosphere containing 1.5% excess oxygen, the treated coal had a coking index of 40 pounds, and the same reduction in volatile matter. Under 640° F. and an atmosphere of 2% free oxygen, the coking index was zero but the loss of volatile matter was 7 points, that is, a reduction from 34% to 27%.

While at present the work is still incomplete it does not seem possible to reduce the coking index to zero in the time allowed—which is 35 seconds—without too great a loss in volatile matter. But the reduction of the coking index to this extreme degree is unnecessary, because a treated coal with an index of 40 produces a semi-coke of a suitable fineness. This has

been accomplished at a temperature of 540° F. and an atmosphere containing 5% excess oxygen. Treatment under such conditions results in a loss of volatile matter of less than one point.

The operation of the primary retort resolves itself into simply introducing pulverized coal by means of star wheel feeders into the top of the retort, allowing it to descend through upwardly rising hot oxidizing gases, collecting the treated coal in the feed hopper of the secondary and exhausting the gases from the retort by means of a fan and venting them to the atmosphere. The oxidizing gases are supplied by introducing air into the bottom of the retort so that they blend with the hot products of combustion coming from the combustion chamber.

The operation of the secondary retort is quite similar to that of the primary. Instead, however, of introducing air as is done in the case of the primary, a combustible gas, which is a part of the rich gas from the process, after first passing through the coke cooler where it is preheated, is introduced through the side inlets of the combustion chamber. This sweeps the heat from the combustion chamber, reduces the excessive flame temperature and provides the necessary weight of gas at a temperature of 1500° F. to carry the desired amount of heat. The gases from the secondary retort are removed by the usual gas exhauster and are then delivered to the gas handling and purifying equipment.

The temperature within this retort is maintained at an average of approximately 1050° F. and this has been found sufficient to reduce a preheated coal containing 34% to a semi-coke containing 10% to 12% volatile matter.

Estimated Heat Required for Carbonizing

The coal when introduced into the primary retort has a maximum moisture content of 1½%. In passing through the retort this moisture is driven off and, as already stated, the coal is preheated to 500° F. As the products of combustion from the fuel gas and the moisture from the coal leave the retort at a temperature of only 250° F., the amount of heat carried out of the retort is reduced to a minimum. Under these conditions the heat required in the primary retort is calculated to be 240 B. t. u. per pound of coal.

As the coal passes into the secondary retort at a temperature of 500° F. and leaves at a temperature of 1100° F. it is necessary to raise the temperature of the coal only 600° F. The temperature of the exit gases from

the retort is 550° F. These exit gases consist of a mixture of the products of combustion from the fuel gas, the circulating gas and the process or make gas.

The amount of heat required in the secondary retort has been calculated as 295 B.t.u. per pound of coal. This quantity of heat, however, is not all supplied by the fuel gas, for the circulating gas is preheated to 1000° F. by passing it through the heated coke. The amount of heat recovered from the coke is calculated as 145 B.t.u. per pound of coal processed. Thus the fuel gas must provide only 150 B.t.u.'s per pound of coal processed in the secondary retort.

These calculations show that the amount of fuel gas required in both the primary and secondary retort is 390 B.t.u.'s per pound of coal processed. The retorts have not been sufficiently long in operation to substantiate these calculations, but the observations so far made indicate very strongly that they will be approximately correct.

Quality of Gas from Process

In calculating the quality of the gas from the process it has of course been necessary to make some assumptions. These assumptions are as follows:

1. That the circulating gas is preheated to 1000° F. in the coke cooler.
2. That the initial fuel gas and circulating gas is a gas with a calorific value of 134 B.t.u.'s per cubic foot, which gas may be obtained from any ordinary type of producer.
3. That the quantity of process gas produced is 3730 cubic feet with a calorific value of 858 B.t.u.'s per cubic foot. This means a total B.t.u. in the process gas of 3,200,000 per ton of coal processed.

As the circulation of gas continues, the calorific value and mean specific heat of the gas vary; thus until a balance or fixed B.t.u. in the gas is reached, the amount of fuel gas and circulating gas must also vary. This is best illustrated by the following example showing how the gas varies from one cycle to another, using a 134 B.t.u. gas as the gas for starting.

To provide sufficient heat per ton for carbonizing in the secondary retort, the products of combustion that are produced total 3480 cubic feet. These, mixed with the circulating gas and the gas from the process, pro-

duce a mixture with a B. t. u. of 252. This gas in the second cycle replaces the producer gas, with the result that the products of combustion are reduced to slightly less than 2800 cubic feet. This results in a mixed gas of 340 B. t. u. This change continues with a gradually decreasing increment until the fourteenth cycle, when it becomes stabilized. In this cycle there are only 2300 cubic feet of products of combustion and the mixed gas has a value of 530 B. t. u.

Studies have been made whereby the gas used in the process is superheated to a still higher degree and also where oxygen is substituted for air in the combustion of the gas, and it is quite apparent from these that a gas containing considerably in excess of 600 B. t. u. can be produced.

The amount of heat required in this process should be less than that required in other processes for several reasons.

1. Because heating and carbonizing is done by direct contact and not by passing heat through brick work or iron.
2. Because the heating is done in two retorts, the first of which heats the exit gases to only 250° F., while the second heats the exit gases to only 500° F.
3. Because the amount of radiation from retorts and combustion chambers is very low.
4. Because the particles of coal are very small the heat penetrates each piece very quickly and carbonization is almost instantaneous.
5. Because a large part of the heat in the coke is recovered for use in the process.

SEMI-COKE

This semi-coke consists of spheroids that are substantially hollow and which have been named "cenospheres" by the English investigator, Sinnatt. The crust is extremely thin and contains numerous pores and openings, many of which are covered with a varnish-like film, and these Sinnatt calls windows. The spheroids are extremely fragile and the larger ones may be readily reduced to a dust by rubbing them between the fingers.

Only a few qualitative tests have so far been made and these indicate that with the semi-coke the boiler rating is considerably increased over that obtained when using pulverized coal.

One of the problems that arises in connection with the treatment of pulverized coal by hot gases is that pertaining to the dust carried by the

gases. In building the Milwaukee unit, which is so much larger than the development unit, it was fully realized that such a problem might arise; but the quantity of dust was a more or less unknown amount. It was obvious that the quantity of dust that would be carried from the retort would depend entirely upon the velocity of the gases passing therethrough, and it was therefore endeavored to maintain it at a minimum. Thus in the main body of the secondary retort the velocity of the gases is estimated at 4.4 feet per second. In order to reduce this velocity and to permit the dust to settle out of the gases, the retorts are flared outwardly, as previously described, and at a point just below the gas outlet have an area 3.6 times as great as the cylindrical portion, thereby reducing the velocity to .85 feet per second. In the primary retort the velocities, of course, differ somewhat due to the change in the temperature employed, and these velocities for the main part of the retort are 6.6, while for the upper or flared portion they are 1.1 feet per second. It is only during the past few weeks that it has been possible to obtain any data as to the quantity of dust that was being taken out by the gases from the process. By careful measurements and some weighings it has been found that the loss varies between ½% and 1%, and that 60—75% of this settles out in the primary system. All of this dust settles and collects in the gas lines leading from the retort to the fan, and no dust is visible from the exit of the primary retort, that is, at a point where the gas leaves the stack and is brought into the atmosphere. As no means were provided for baffling or catching this dust, the ease with which it may be removed is evident. A simple dust catcher, whereby the gas is baffled, is now being installed on the primary system. An analysis of the dust shows it to be bone dry and of a fineness such that 100% will pass through a 200-mesh screen.

It is natural to suppose that if it is only the fine material that is being removed by the gases the quantity of dust appearing in the secondary system would be greatly reduced, and this is actually the case. There is, however, a small amount finding its way into the tar, sufficient in quantity to reduce the value of the tar. Steps are now being taken whereby the dust may be separated from the tar while the latter is still in the vapor

form, and assurances have been given by a manufacturer of equipment that this can be satisfactorily handled.

CAPACITY OF THE MILWAUKEE UNIT

The rated capacity of this unit is 210 tons per day, and prolonged runs have been made at a capacity of nine tons per hour, which is slightly greater than the rated capacity. This, however, is only slightly more than 50% of the estimated capacity based on results obtained with the development unit. This unit, with a diameter of 12 inches and a height of 30 feet, ran at a capacity of 350 pounds per hour. Taking into consideration the much larger diameter and the dual retort system, the commercial unit has an estimated capacity of 16 tons per hour, or almost double that of the rated capacity.

Labor

At present the plant is operated with sixteen men per 24 hours, five men per shift and one boss foreman. It is quite probable that this can be reduced to thirteen men, and maybe even less.

While some of the special features of this process have been pointed out, it is well to mention another important one—namely, that the unit contains no mechanical parts that move within the heat treating or carbonizing zones. The danger, therefore, of frequent shut-downs is eliminated and any repairs that are necessary are for readily accessible parts, which can be made quickly without losing the heats in the retorts.

Another interesting feature is the flexibility of the retorts, whose throughput may be changed at a minute's notice from a minimum to a maximum, or vice versa.

In conclusion, it may be stated that while the work on the Milwaukee unit has not progressed to the point where all questions have been satisfactorily solved, it has established that the principles involved in the processes are correct.

THE GREENE-LAUCKS PROCESS

By F. C. Greene
Old Ben Coal Corporation, Chicago

From the literature and from observation those of you studiously interested have discerned certain fundamentals necessary in carbonizing coals at low temperatures. I hope your recognition and approval of the manner employed in this process to conform to such fundamentals will follow from a description of development at the Old Ben Coal Corporation pilot-plant at Waukegan, Illinois, where, for some two years several thousand tons of southern Illinois screenings were converted from a low form-value to a high form-value.

Low temperature fuels are notoriously weak, spongy, light-weight, rapid-burning—qualities undesirable in the domestic market however much such character may satisfy other markets. Old Ben's trade is almost solely domestic. Such trade required heavy, strong, dense, smokeless and clinkerless fuel that would ship like the strongest coals and burn as well, or better than, the highest grades of anthracite or Pocahontas coals.

To show you how such desirable conversion was effected I ask your attention to Figure 1 showing the apparatus at Waukegan. The operation is continuous, producing very dense strong lump char by passing a thin stream of coal upward between two heated surfaces, by means of a screw, or rotor, turning slowly within a vertically suspended circular retort. The retort is eighteen feet long. It is three feet in diameter at the bottom and flares to somewhat larger diameter at the top. The retort is externally heated. The rotor is internally heated. The limits of heating are such as to distil off the condensible vapours without cracking same to gas. But one moving part in the heated zone is employed.

Figure 1-a will give you a photographic view of a rotor as being pulled out of the retort. Many hundreds of such pull-outs enabled us to study and determine just what happened to the coal in its conversion. Note the three threads, or flights, of the rotor wound with increasing pitch from bottom to top. Also note that whilst the shaft of the rotor is 30 inches, the flights are somewhat wider at the top than at the

bottom. Three inches width at the bottom is a favorable compromise for thin-wall carbonizing; one of the fundamentals. The pitch of flights at the bottom is 12 inches. At the top it is 16 inches. This not only gives easement to the swelling coal but also facilitates withdrawals of the rotor and, possibly most important, permits space for exit of vapours. At the top ejector blades discharge the char.

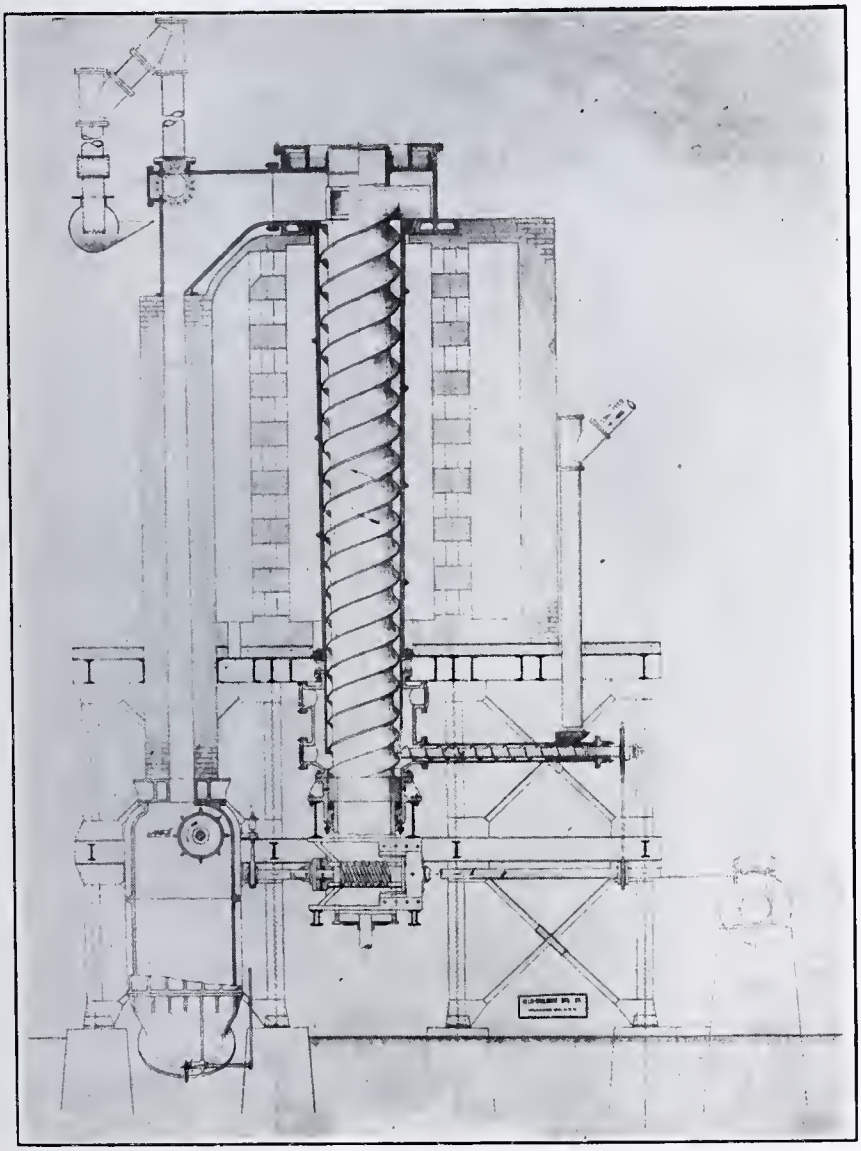

FIG. 1. SECTION ELEVATION 3-FT. G. L. P. CARBONIZING RETORT PILOT PLANT

Fig. 1a. A Rotor

Returning to Figure 1 it will be noted that the rotor rests on a bearing which is always cool. The coal is fed to the rotor by a short conveyor above the bearing. Tangential delivery against the rotor rotation seems most satisfactory and suitable synchronizing is provided. Gradation of furnace heating is, of course, fundamental—as will be shown later. The top housings for exit of char and vapours require attention to such points as seal, elimination of dust, prevention of too early condensation, and so forth—more or less classic. The foregoing elements of construction are essential. Other incidental parts may be understood as I describe the functioning of the apparatus.

The functioning is shown by Figure 2. The coal screenings are anything from dust to 2″ size, fed in a more or less dry state to the rotor. This dry coal, relatively cool, acts as a condenser and heat receptacle for the down-coming steam which is generated at considerable super-

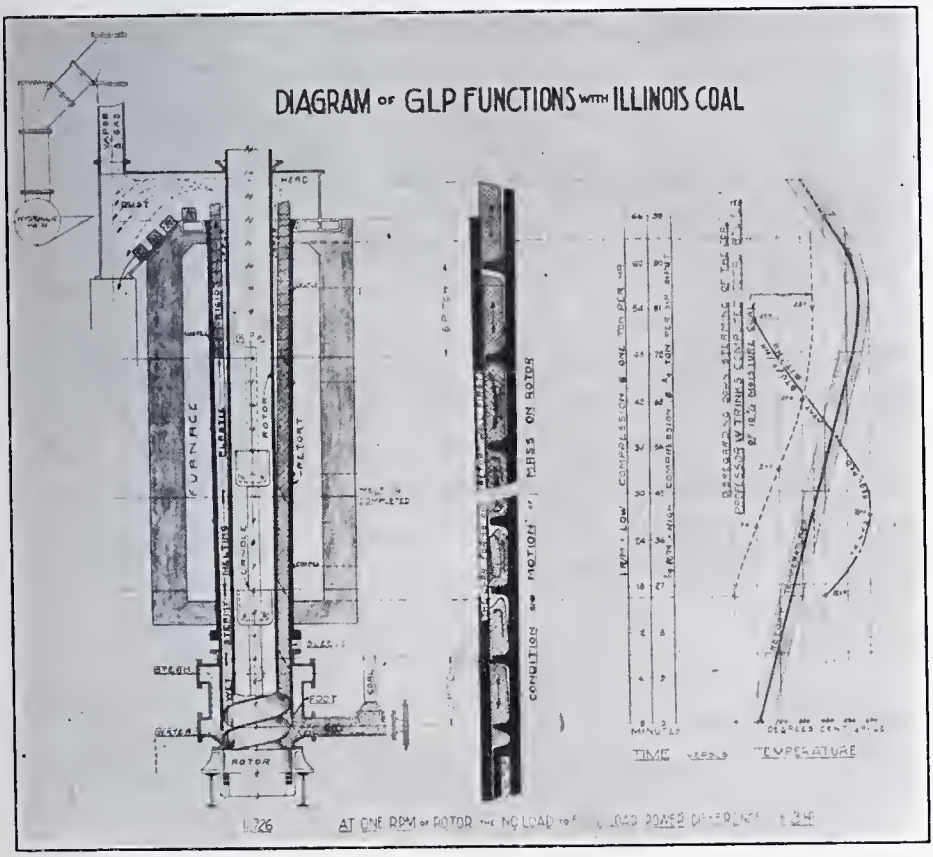

FIG. 2. DIAGRAM OF G. L. P. FUNCTIONS WITH ILLINOIS COAL

heat and pressure in the "steamy" zone. But little visible steam makes exit from the foot. It is mostly condensed to tepid water having a distinct musty mine-odor. No hydrocarbon vapours come downward. In the steamy zone the mass is doubtless levitated, steam-dry and preheated almost to its melting-point ready for complete melting under the furnace temperatures. Turbulence of the mass occurs under the screw action, thus assisting heat reception. By reference to the graph of heat requirement you will see that the maximum impressment of heat takes place in the melting zone. During this period the mass melts first on the retort wall. The melted part is scraped off by the rotor flights. It twists and turns sluggishly, thus presenting fresh unmelted surfaces. The diagrammatic representation of the condition of the mass at a given point is exhibited by Figure 2. Dissection of the mass on the rotor, when pulled out quickly, enables this representation of motion and condition. The zone marked "plastic" is that in which the gummy mass is boiled—distilled. Here the melted coal completely fills the annular space between rotor and retort walls. It tends to swell. Unrestricted it would form very large cells. Its restriction causes pressures of the order of one thousand pounds per square inch. Thus the mass here forms a seal between the downward going steam and the upward-going vapours. We employ adjustable heat impressment in this plastic zone to reduce or increase the restriction of cell structure. In this zone is where the usual sticking or gumming of an unheated screw occurs. Naturally a cold surface will condense the vapours to a highly adhesive condition. Keep the surfaces above the condensation point and lubrication is effected.* Hence the internal heating of the rotor in a selective manner. About 50 percent of the retort heat is thus impressed from the rotor wall. Pyrometric control of external and internal heating has been used, but the operatives largely depend upon color of the retort or rotor, or upon such remote indications as the temperature of the waste heat flue. Another practically used indicator is the power ammeter. Gradual increase of power indicates lowering temperature of rotor—and vice versa. Such changes take place very gradually. The weight of metal to weight of coal being twenty to one acts as heat storage. Given a fairly steady supply and thermal value

* You may demonstrate the principle employed by sliding a redhot poker over a lump of bituminous coal.

of gas the apparatus functions indefinitely with but slight attention by the operative.

The distillation of the hydrocarbon vapours is normally completed some six feet down from the top of the retort. Why not eject the mass there? There are several good reasons against so doing. The deciding factor is variation of free moisture content of the coal. High moisture moves all zones higher in the apparatus. The position of zones shown is in average of ten pull-outs taken at random. The variation therefrom may be a few feet up or down depending upon the free water of the coal. Evidently one expects lengthened plastic zone with increasing volatile of the coal—or rather we should say, with increasing resin content of the coal. Another objection against reducing length of retort is a well founded belief that merely boiling off the hydrocarbon vapours does not complete the formation of true low temperature char of great strength. Above the plastic zone (in that zone marked "rigid") exothermic reactions occur. They must be permitted to run their course otherwise the char, whilst dense and hard and heavy, will yet tend to fracture. If exothermicity is not stopped by cooling in the rigid zone then the product becomes extremely tough and will stand severe handling without notable degradation. You will see that whereas each pound of coal has received its quota of heat in the melting zone, yet the retort temperature continues to rise although no extraneous heat is applied.

By referring to the time tabulation two methods of operating the apparatus are shown. Thus, at one ton per hour input coal, with the rotor turning one revolution per minute, low compression char is made in about one hour, whereas at three-quarters revolution of rotor with high compression a reduction of coal input to three-quarters of a ton per hour results. Conceivably, with the elements of temperature, time, pressure, turbulence, and so forth, under control— as is the case with this apparatus—a great variety of desired product is obtained.

A study of the time function may be made from the graphical representations of Fig. 2, but I will not impose further upon your patience.

The exit of the hydrocarbon vapours is by way of the annular helical spaces between the rotor wall and the plastic mass. As the plastic mass becomes more and more viscous—or leathery—it hugs the retort wall which you will recall is flared outward increasingly to the top of

retort. Hence the vapour space. Along this passage but slight evidences of amorphous carbon are noted upon pulling out a rotor. Furthermore the small quantity of fixed gas made (averaging 1,000 cubic feet per ton of coal) indicates negligible cracking of the hydrocarbon vapours. The primary tar recovery of the apparatus is thus highly efficient.

The vapour pressure in the head of the apparatus is usually maintained at a few tenths of an inch of water. The foot pressures vary with free moisture of the coal but are usually also slight. No attempts have been made to secure great negative or positive pressures referred to the atmosphere, but some interesting results may develop in the future by research work with pressure and other allied functionings in this flexible apparatus.

Rapid carbonization of coal produces dust which, if not suitably caught, reaches the hydraulic main and causes trouble there or at some farther-on point in the plant. We settle the dust out of the vapour stream onto the discharging char which latter also receives a slight drip of dusty pitch from the vapour riser pipe. The char readily absorbs this with no noticeably bad effect. The char is allowed to cool slowly in a large air-tight chamber before discharge to the air—at hand temperature. At the pilot-plant no effort was made to handle it gently, drops of twenty feet or more into the cooling chamber being tried out for effect upon strength. In the large commercial plant at Old Ben's mines in southern Illinois

Fig. 3. Density Comparison of High Temperature Coke and Char

we shall handle the char more discretely. However, the experience gained in rough handling the char was of value in determining just how much braize could be added to the raw coal and recirculated through the apparatus. It was found that as much as 35 percent of the feed could be of braize and yet produce a strong char of great density and of desirable slow-burning qualities. Thus we shall recirculate all braize and have none sent to waste piles nor to the market.

The density of the usual char produced for the domestic markets is compared in Figure 3 with that of high temperature coke. It is quite possible to make char almost as dense as is the original coal, but we were quite well satisfied to obtain 90 percent that would sink in water when running at normal compressions. Without such compression of cell structure 100 percent will float.

The input capacity of this pilot-plant (three foot size) apparatus, running steadily over long periods, averaged fifteen tons of raw coal plus an admixture of three or four tons of braize, during the twenty-four hour day. This admixture of braize with southern Illinois coal was believed to result in the optimum product acceptable to our domestic trade since it rendered the char entirely clinkerless from a coal with 2,300°F. low fusing-point ash.

Manifestly the char yield depends upon the extent to which devolatilization of the coal is carried. For our almost solely domestic market we consider the ultimate consumer better pleased with product having volatile content just inside the limit of smoking. This volatile content may be between 15 percent and 20 percent, averaging, say 18 percent. Thus made the yield will vary between 70 percent and 80 percent of the original coal weight. Our efforts in this direction resulted in extremely low gas yields. Usual low temperature carbonization of coal yields between 3 M.c.f. and 8 M.c.f. per ton of coal. Gas made from our screenings was kept as low as average 1,000 cubic feet per ton; at which period its calorific value averaged 862 B.t.u. per cubic foot at normal temperature and pressure.

You will have noted from Figure 2 that some 350 B.t.u. is theoretically sufficient to carbonize one pound of coal at low temperature. In practice we found we could carbonize with 1,000 B.t.u. roundly, per pound of coal input. Thus, less than 10 percent fuel consumption in carbonizing was satisfactory, representing a furnace efficiency over-all which may doubtless yet be improved upon.

Tar yields are dependable upon the resin content of a particular coal. Avoidance of cracking the vapours to gas is essential of course. Southern Illinois screenings with ten percent ash and ten percent water contents will yield in this apparatus roundly 20 gallons of liquid hydrocarbons per ton of coal. Some 12 percent of this quantity is light-oil. The fractionating of the tars has shown their favorable commercial adaptation, but with the petroleum situation existing in this country we rather favor cracking the entire tar to gasolines and refluxing the residuums in the retorts with coal and braize, where further molecular rearrangements of value seem feasible. The subject of tars does not enter into the objective of Old Ben in the establishment of this Greene-Laucks process at the mines, nor does gas nor ammonia. True low temperature char itself carries most of the nitrogen, but as sulphate of ammonia probably 10 pounds per ton of coal might be expected. Other methods of nitrogen fixation are of more importance.

At this stage of the presentation of this paper I should doubtless exhibit an evaluation of the foregoing products; what the conversion costs are; in short, to statistically prove it worth the investment to carbonize screenings at low temperature. Old Ben Coal Corporation, the sole owner of American rights in this process, of course kept very full records of performances, costs and realizations at the pilot-plant. A liberal discounting of present day margins in the conversion assures Old Ben sufficiently of the commercial value of low temperature carbonizing to authorize construction of plant at mines on a carefully planned unit-basis which will ultimately handle a very large daily tonnage. The pilot-plant has been removed to the mines and the engineers are preparing the details of construction entering into such unit-basis plant. The experience gained at the pilot-plant has enabled the engineers to determine the maximum size equipment, limited by transportation problems to retorts nine feet in diameter by eigheet feet in length. This size minimizes the investment and labor costs and does not introduce any unknown factors of construction or operation. The peripheral contact speeds, flighting, heat impressment gradients, et cetera, are identical with the pilot-plant apparatus. President D. W. Buchanan, of Old Ben Coal Corporation, aptly describes the nine foot size apparatus thus:

"We unroll three three foot size rotors, join them, roll them up into one nine foot nine flighted rotor and insert in a nine foot retort."

Here and there improvements so obvious as to remove them entirely from the status of experiment have been made. Figure 4 indicates the notable reduction in over-all height. The nine foot rotor is directly supported by the foundations. Concrete sub-structure has replaced the former steel structure supporting the furnace. The external furnace from designs furnished by Professor W. Trinks employs a multiplicity of gas burners suitably dispersed to

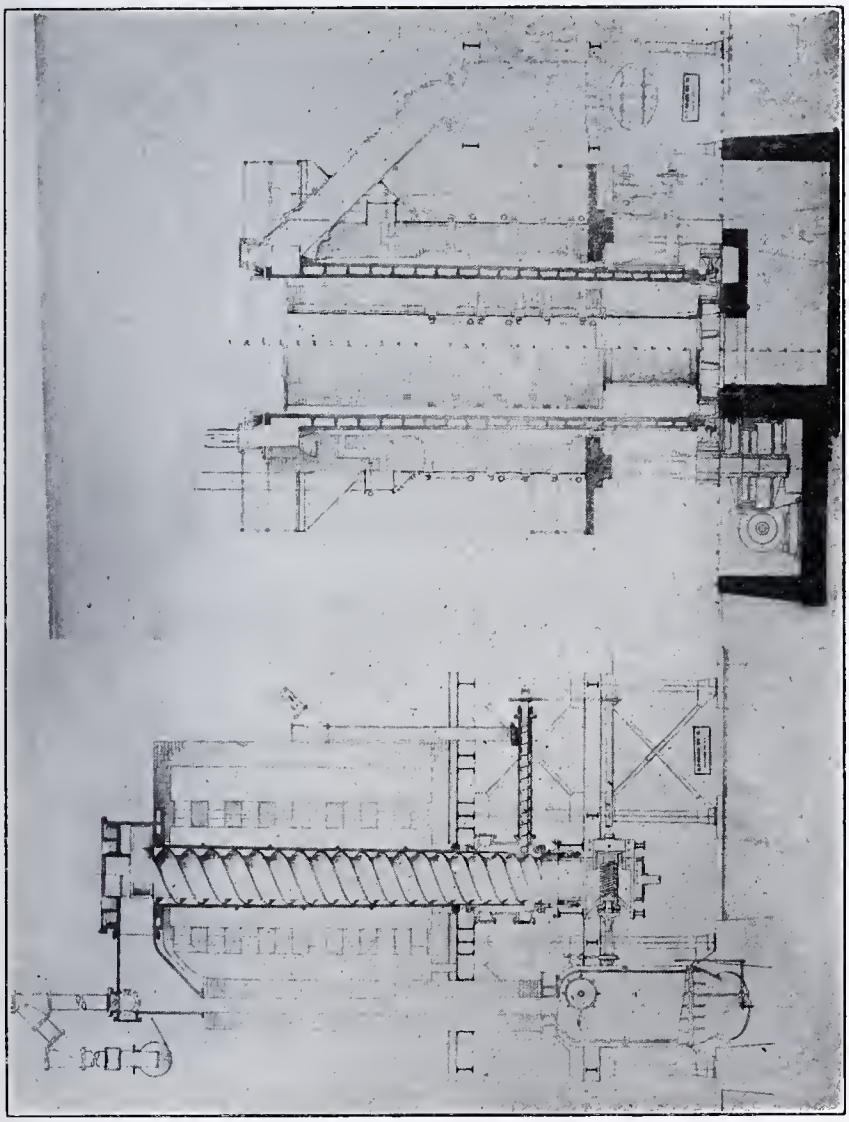

FIG. 4. REDUCTION IN HEIGHT WITH CONCRETE SUB-STRUCTURE

give the heat gradients proven desirable in the pilot-plant, and to result in very uniform heating of such a large cylinder. Neutral or reducing furnace atmospheres are assured and a probable reduction of fuel consumption. The pilot-plant furnace has one combustion chamber from which baffled ports permitted zonal heat adjustment whereas the nine foot size furnace combustion is completed at each burner and batteries of burners are controllable by master valves. Figure 5 illustrates somewhat more plainly the nine foot size retort constructions. Replacing the "candle" of the three foot

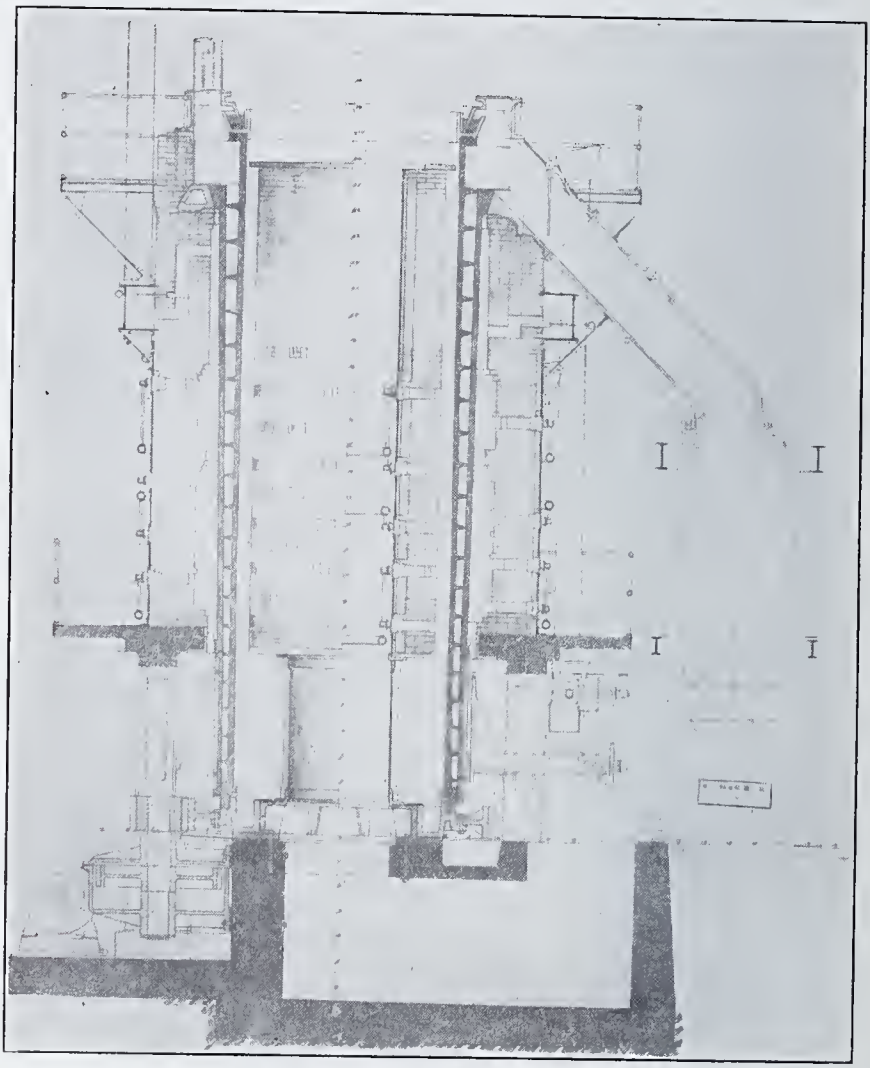

Fig. 5. Nine Foot Size Retort Construction

size an interior furnace of brickwork functions in manner similar to the exterior furnace. The massive rotor has nearly direct connection to a variable-speed motor and the four feed-screws are similarly driven, all thus insuring highest power efficiency, and synchronous adjustment. The two years operation of the pilot-plant demonstrated that temperature suited to low temperature carbonization would not even slightly deteriorate the cast-iron

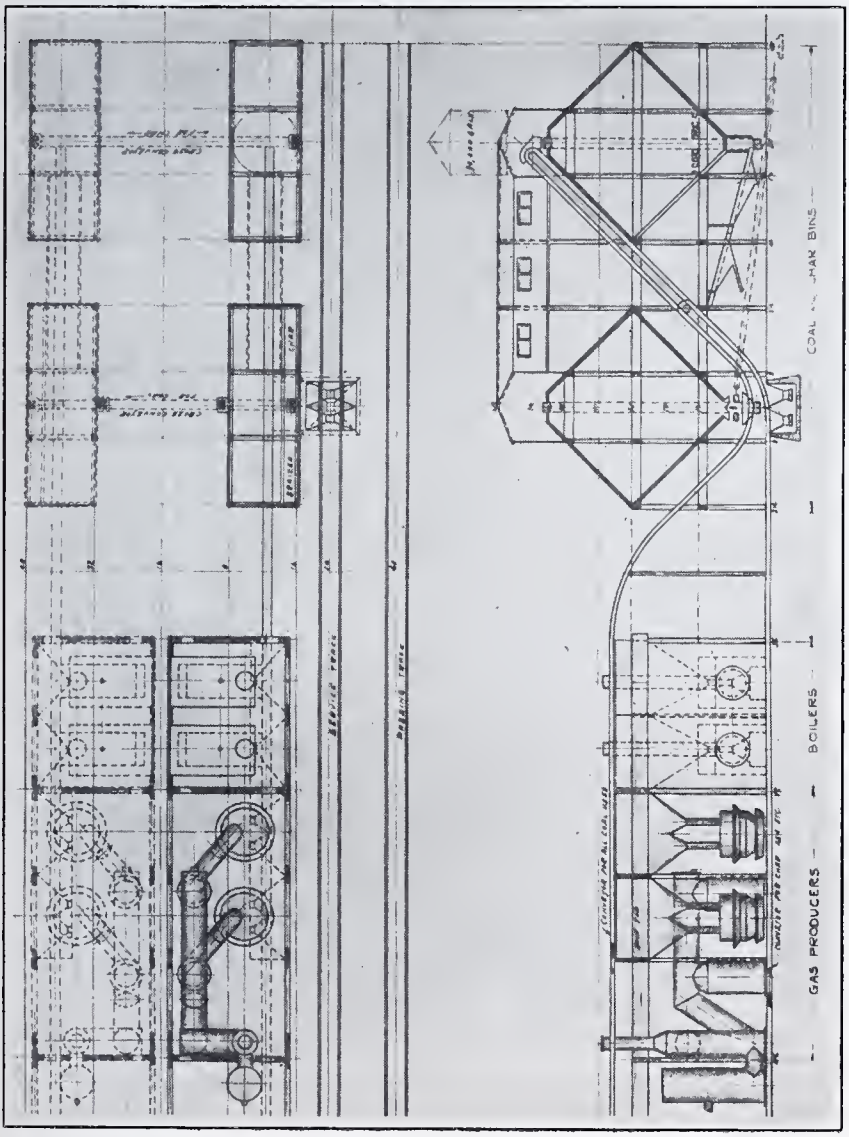

FIG. 6. RECEIVING AND DELIVERY SECTION OF PLANT

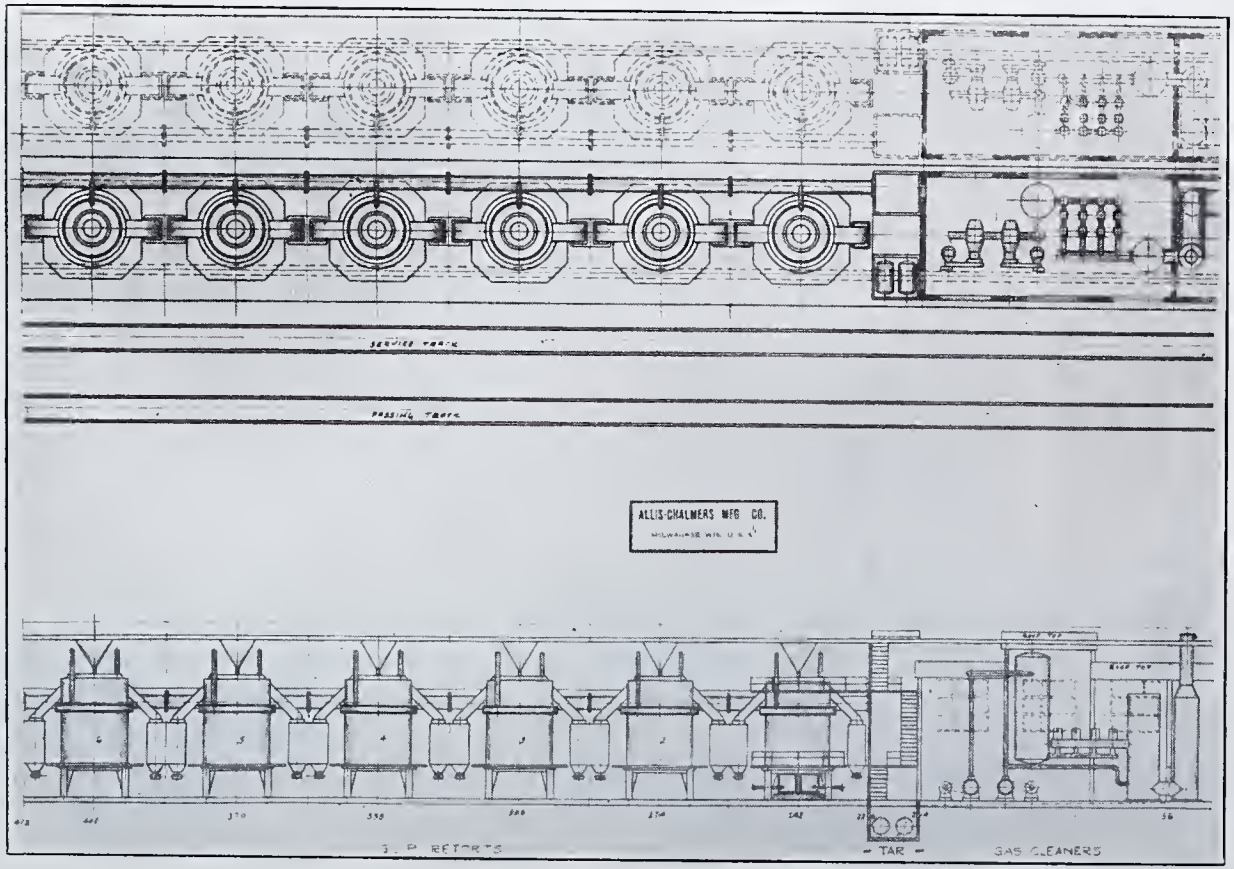

Fig. 7. Retort Battery

parts under heat. Note that the retort expands downward and the rotor expands upward. Permanent growth of metal is readily accommodated.

Such retort settings are proposed then in batteries of ten for each 500-ton daily capacity unit plant. In the figures illustrating this unit plant it will be seen that a common center-line layout permits maximum service in construction, operation and replacement, by traveling shear-legs, or gantry employing simple blocks for handling heavy equipment. The straight-line layout also allows of approved form of an "all-purpose" conveyor serving input coal, out-put char and braize, auxiliary steam and gas-producer plants fuel, etc. Modern labor-saving as well as capital-saving standard equipment is used throughout. A number of prominent manufacturing engineers have collaborated in this plant design. The clearing-house for such technicians is the Allis-Chalmers Manufacturing Company of Milwaukee who constructed the pilot-plant retorts and assisted in the development work at Waukegan, and who are now doing the general engineering work for Old Ben's carbonizing projects.

Figure 6 shows the receiving and delivery section of the plant. Track-hoppers receive the screenings from railway cars. The coal is elevated to raw coal bins beneath which proportioning belts deliver the determined portions of coal and braize to the all-purpose conveyor mentioned. This conveyor fills bins at each retort—sufficient for one or more shifts. It is a very slow-moving mechanism. The slight over-capacity coal is dropped to its lower run at the far end and returns with the char and braize from each retort as discharged. The run-of-retort char may be delivered with any desired sizing through the screening plant direct to the railway cars or binned. The binned char may be re-screened. The over-capacity coal together with degradation of char from retort, bin or screen sources is returned to the braize compartment of the coal bin or may be sent forward to the steam plant. The gas-producers receive dust-free nut size coal and their ash is handled by the all-purpose conveyor. Railway scale weights will record inputs and outputs. The structures are mainly of reinforced concrete. The char-bin center-line may also be a duplication center-line; or, if large ground storage of char is required such area would be between duplicate

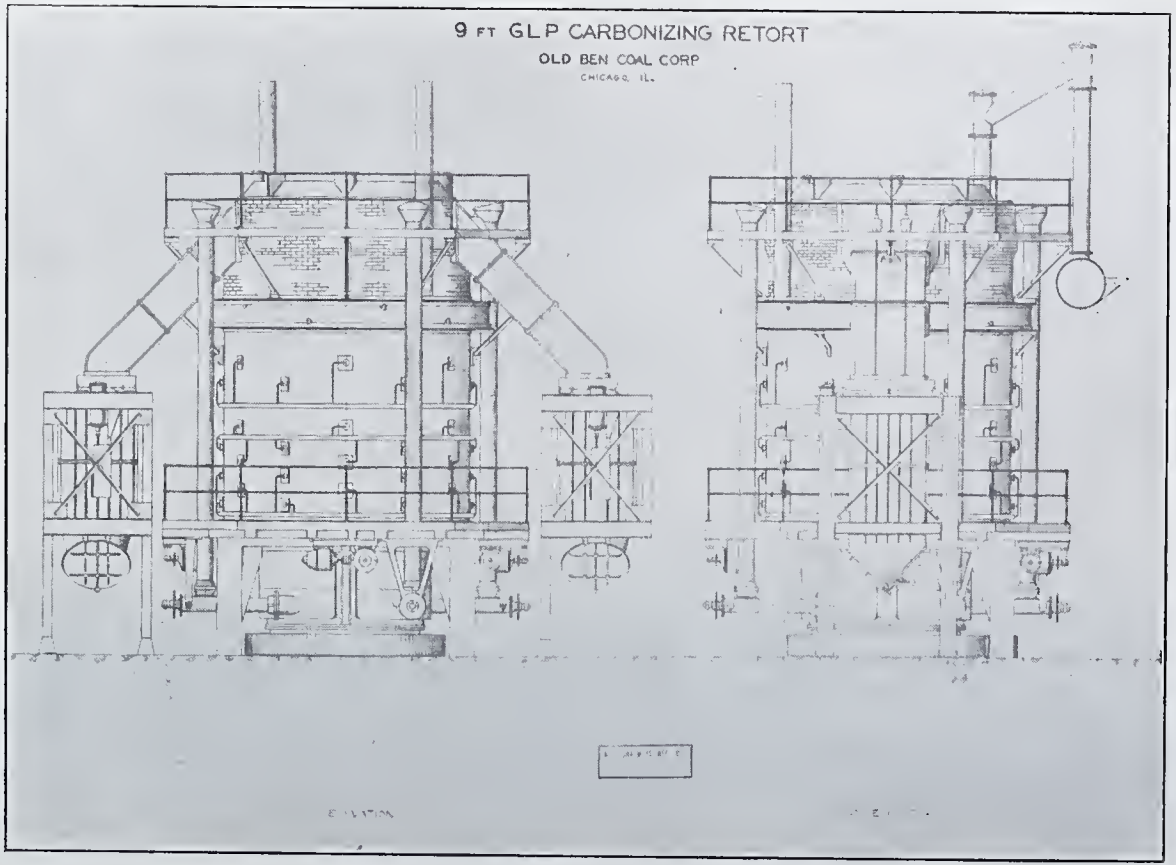

FIG. 8. 9-FT. G. L. P. CARBONIZING RETORT

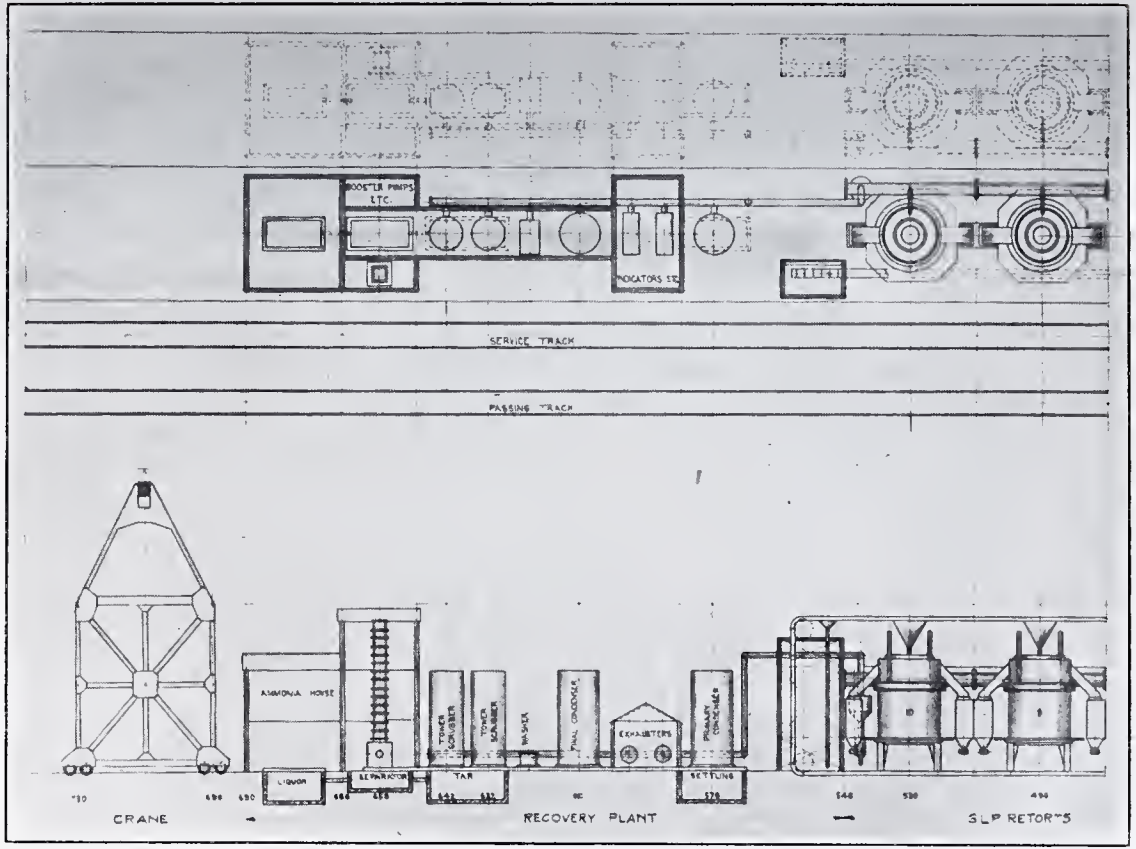

FIG. 9. RECOVERY PLANT

right- and left-hand plants. The Link-Belt Company Engineers ably collaborated in the foregoing details.

The steam plant requires no detailed description; but, it may be noted that the unit-basis of construction placing similar elements in on the same cross-centerline, avoids unnecessary duplication of labor charges.

Flynn & Dreffein design of Clean Producer-gas Plant is incorporated in the layout. Here the high B.t.u. retort gas is mixed with the producer gas and, by an ingenious method of duplicating the retort burners action, uniformity of firing control of the retorts is continuously registered. All piping is carried on structural rack-posts which also support the hydraulic main independently of the retorts. The average B.t.u. of mixed gas will be about 220 per cu. ft.

Figure 7 shows retort battery of ten and the next adjacent ten units. Figure 8 shows exterior appearance of these retorts. Figure 9 shows the recovery plant of standard construction. The Gas Machinery Company of Cleveland furnished its design. The shear-legged gantry crane is also shown after design by Wisconsin Bridge & Iron Company. Such incidental equipment and constructions as are usual or conducive to economies—employees' conveniences, office, stores, shop, heating, steaming, communication, sanitation, etc., though not shown, hardly require more than listing. Every modern plant finds such items a good investment.

THE PIRON COAL DISTILLATION PROCESS

By Emil H. Piron
Consulting Engineer, New York
AND
Robert M. Crawford
Chemical Engineer, Pittsburgh, Pa.

It was not our intention to publish anything concerning our activities in low temperature distillation of coal because the oven we have now in construction in Italy is not yet completed. But Dr. Baker, your president, asked us to report our experience in such a way that it would have been difficult to refuse.

We came into the low temperature game a few years ago with an idea we thought was good. We built a small demonstration oven in Huntington to see how it would work. That demonstration oven made a good showing and so a contract was obtained from the Ford Motor Companies of Detroit and Canada for the construction of large ovens of that type.

There is one thing that dominates everyone approaching Mr. Ford's organizations. It is the scale on which one has to work. We had to start big from the beginning. That made the work much more difficult, but on the other hand it enabled us to learn things we never would have learned possibly in a lifetime if it had not been for this incursion of Mr. Ford in that field.

With the highly valuable and most effective coöperation of two giant organizations, the Ford Motor Companies of Detroit and of Canada, we built two large ovens, tested them, changed them, operated them and got results controlled with all the facilities of the most modern industrial methods.

The construction of the Canadian oven went rapidly. But an accident happened right at the start. For want of gas in the Canadian plant, the oven was heated with oil burners and its cast iron flues were burned out before the oven could show a run of any duration.

Later, the River Rouge oven which was heated with gas proved that the accident of the Canadian oven was solely due to the oil

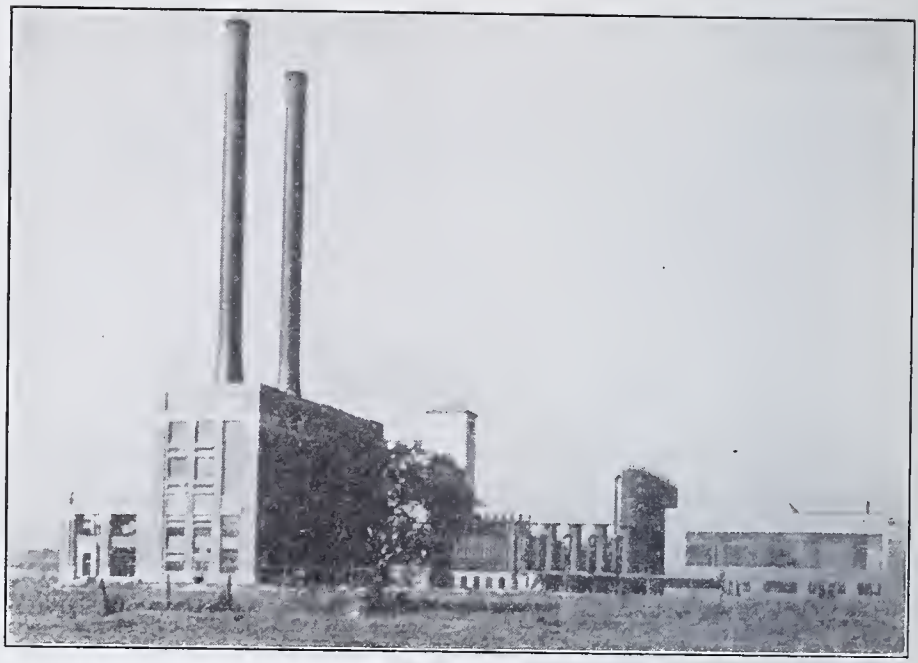

FIG. 1. GENERAL VIEW OF WALKERVILLE, ONT., POWER PLANT OF FORD MOTOR COMPANY OF CANADA.
Showing the Piron retort, condensers, coolers, and by-product house at the right center.

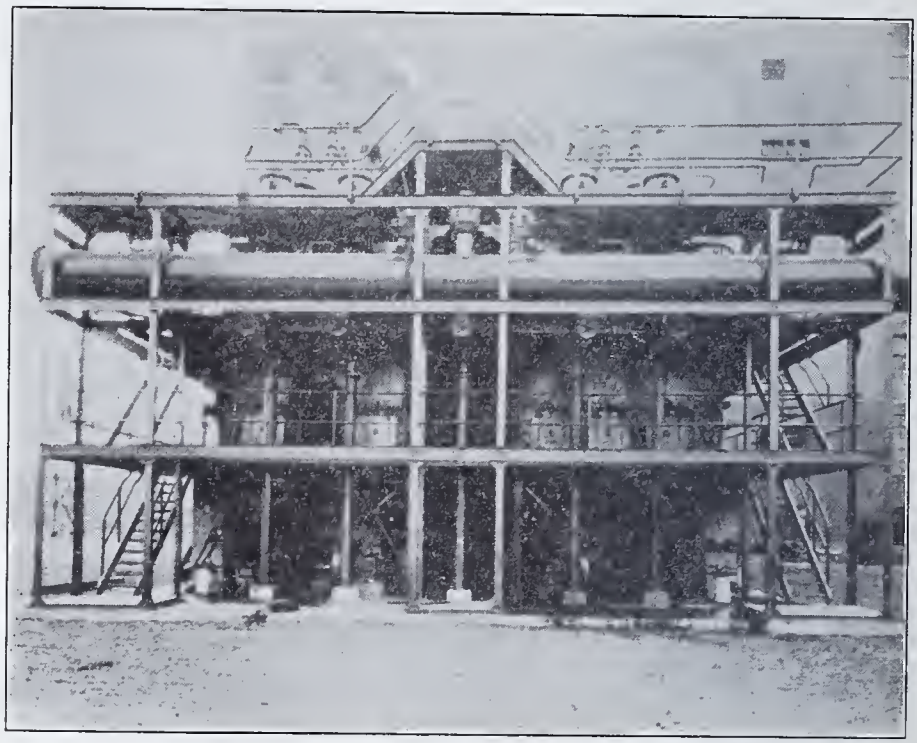

FIG. 2. END ELEVATION OF WALKERVILLE, ONT., RETORT

burners, because the Rouge flues resisted perfectly. But we did not know that until the Rouge oven had shown it, and the Canadian oven was rebuilt with alloy troughs replacing the cast iron flues.

During its runs in 1925 the Rouge oven distilled 3,000 tons of coal.

The reconditioned Canadian oven in two runs distilled 850 and 1,350 tons respectively.

Our oven can be divided into four main parts—the coal feeder, the conveyor and its sprockets, the heating system and the coke discharge.

The first and last parts, i. e., the coal feeder and coke discharge, gave trouble at the beginning. It was hard to feed to the conveyor a coal layer of the thickness and uniformity we needed, and then there were difficulties in preventing coke from piling up in the discharge end of the oven. These difficulties were overcome by the work done at River Rouge, which showed us how to build a perfect feeder and a safe coke discharge.

Advantage was taken of the River Rouge experience for the rebuilding of the Canadian oven in which feed and discharge troubles were never experienced.

It will be noted that the regulation of an automatic and continuous apparatus for the distillation of coal, especially the regulation of the distillation process itself, is almost impossible without perfect means of feeding and discharging. If an operation of distillation must be stopped from time to time because of trouble in the feeding or in the discharging, or if the amount of coal fed is not absolutely uniform, conditions of temperature will never be constant. It was the adjusting of those two points that enabled us to succeed in the operation of distillation itself.

The heating system gave us some trouble in the beginning, but this was only a question of burner adjustment without special difficulties as the temperature we needed was very easy to reach and to keep constant.

As for the conveyor that is built of cast iron, we never had a breakdown as long as we kept the temperature not higher than 1200° F. But it was almost impossible to be satisfied with that in a Ford plant where a production of 50 tons per day with one distillation chamber did not seem like anything. We had to increase the production, and to do so, to increase the temperature and run into

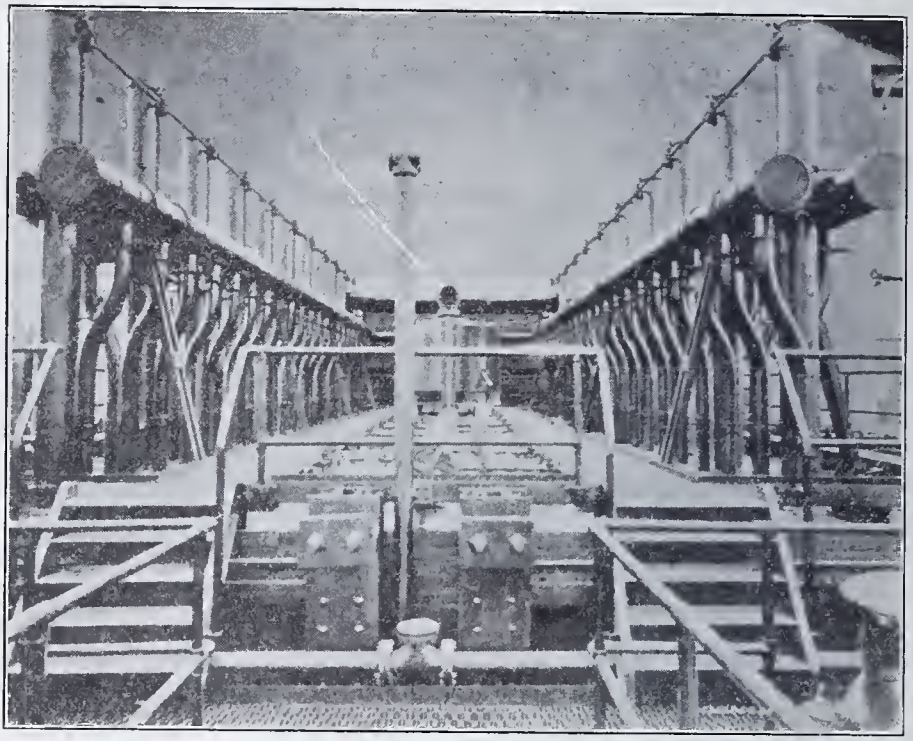

FIG. 3. VIEW ALONG TOP WALKERVILLE, ONT., RETORT
Showing gas mains, flues, etc.

breakdowns. But these breakdowns themselves have taught us more than anything else. They have shown us the weak points of the oven and given us plenty of opportunities for inspection and adjustment.

The Ford ovens were inspected during their operation by a number of engineers, and some of them after watching the operation for weeks are now building a first unit in Italy for the Azienda Gas Company of Genoa.

The breakdowns at the River Rouge affected both sprockets and conveyors, while in the Canadian plant they affected conveyors only. As for the conveyor, the way of taking care of breakdowns is evidently to reinforce its construction, which can be done easily, as the Italian oven will show.

Naturally in that oven we take advantage of previous experience. The size of the oven is smaller. Instead of being built of individual units, the oven is built to fit into batteries of any number

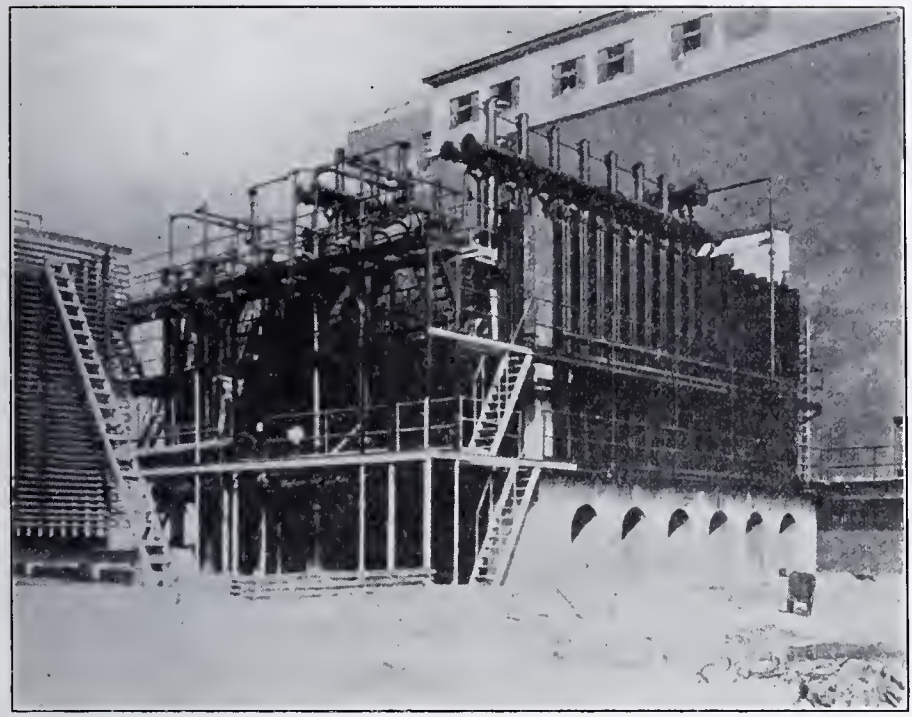

FIG. 4. GENERAL VIEW, WALKERVILLE, ONT., RETORT

of units. All the unnecessary details have been taken out of the design, keeping the construction cost at the lowest possible level. Every precaution has been taken to make that unit absolutely automatic and facilitate constant conditions of operation—that is constant production, constant temperature of coke, gas and tar vapors, and facilities for varying those temperatures within a reasonable range.

The results that are expected from that oven are based on the results obtained with the Ford ovens and are explained in the following outstanding runs of the Ford ovens.

The area of the conveyor's surface used for distillation at River Rouge was about 500 square feet; at Walkerville 400 square feet.

In order to judge the results that have been obtained we consider five periods of run during which little or no trouble was experienced with the feeding of the coal and the discharging of the coke.

These periods are:

A. A 20-day run from August 21st to September 10, 1925, at River Rouge, which distilled 705 tons of coal (all numbers dry basis)

with an average of 35 tons per 24 hours. The coal had 35.3% of volatile matter and gave 73.2% of coke with 11.6% volatile. Reduced to the units we use this makes 5.9 pounds of coal distilled per hour per square foot of distilling surface.

B. A 6-day run from October 15 to 22, 1925, at River Rouge during which we distilled 397 tons of coal with an average of 49.6 tons per 24 hours. The coal had 35.8% of volatile and gave 76.8% of coke with 16.5% volatile. The distillation was not as complete as in run "A" but the production was raised to 8.2 pounds of coal distilled per square foot per hour.

C. A 10-day run from January 1 to 11, 1926, at River Rouge, during which we distilled 441 tons of coal with an average of 44.1 tons per 24 hours. The coal had 35.4% of volatile and gave 71% of coke with 9% of volatile. The distillation was more complete than in run "B" and the production was 7.3 pounds of coal distilled per square foot per hour.

D. A 21-day run from March 2 to 24, 1926, which was the first operation period of the Walkerville oven. The amount of coal distilled was 833 tons in total, or 40 tons per day which amounts to 8.3 pounds of coal per square foot per hour.

E. A 35-day run from April 28th to June 2, 1926, at Walkerville. During that period the oven was stopped during the first four Sundays, making this an actual 31-day run, during which 1,357 tons of coal were distilled at the rate of 43.8 tons per day or 9.1 pounds per square foot per hour. The coal had an average of 38% volatile, 5.4% moisture and 4% ash. The coke had 7.6 to 11.2% volatile with an average of 9.7%.

During all these runs there were a number of external causes reducing the capacity of the oven independently of the oven itself. These causes were mainly tramp iron in the coal. The opening of the feeder slot through which the coal was fed was gradually reduced. The feeder was strong enough to crush through that slot any pieces of coal or stone of larger size, but not a piece of metal. Such pieces of metal simply stopped the feeding until they were removed by hand.

In Italy we intend to screen all the coal coming in through the feeder bin so as to prevent such troubles, but at the Ford ovens such screening was not done.

Feeding interruptions were also more important than they appeared because they were not seen instantly. An unknown time elapsed from the moment they happened to the time the feeder was put again in feeding order.

To have an idea what the capacity of the oven was when feeding normally we made during the first run at Walkerville a number of capacity tests of short duration. These tests showed the following results:

March	8th	Rating,	10	lbs.	per	sq.	ft.	per hour
March	10th	"	11.5	"	"	"	"	"
March	17th	"	13.3	"	"	"	"	"
March	19th	"	14.5	"	"	"	"	"
March	22nd	"	13.7	"	"	"	"	"

It seems that a rating around 13.5 pounds per square foot per hour can be maintained in an oven in which necessary precautions are taken to prevent delays due to external causes. That rating is the equivalent of 62.5 tons of coal per day for an oven of the Walkerville size and 78 tons per day for the River Rouge size.

But we do not try, at the present time at least, to reach such capacities. On the principle that it is easy to build in small what has been done on a large scale, we have reduced the size of the Italian oven from 72′ to 46′ in total length; from 9′ to 2′4″ in conveyor width, and from 500 to 85 square feet in actual distillation surface. With the experience gained in the large ovens, we feel we can build the small size with such coefficient of safety that will do away with any kind of breakdown. The daily capacity of that size is estimated at 15 tons of coal.

Naturally 15 tons would be a small capacity for an oven built in separate or even in double units like the Ford ovens, but this small size is adjusted so as to allow battery construction as in high temperature ovens, and at that rating they will give more production per unit of yard space than the high temperature ovens because they do not require extra space for coke pusher and quenching car service.

The expectations shown above are based on actual runs and show the production we know we can realize. There are other expectations based on laboratory tests which are a basis not for actual projects, but for ideals we try to attain.

According to these tests we can distill a 35% volatile coal with a reasonable amount of moisture (say about 3%) down to a 10% volatile coke at the rate of 19 pounds per square foot per hour. That rating would bring the production of the Italian oven to 19 tons per day, and its realization depends mostly on the uniformity of the feeding. In the laboratory tests the coal was placed on the heated plate with a uniformity that is practically perfect. We must not expect such perfection of uniformity in a coal layer fed from a feeder to a moving conveyor running under conditions in which the means of equalizing the coal layer thickness on the feeder are practically impossible because of the presence of gas and vapors coating everything with carbon, and of the impossibility of controlling equalizing means in that closed chamber.

But if we call the uniformity of the coal layer in the laboratory test 100% then we see that at Walkerville the feeding was 13.5÷19 or 70%, and we expect to improve on that percentage.

It is an open question whether we will be able to transmit to the conveyor the amount of heat sufficient to take care of a distillation of 19 pounds of coal per square foot per hour; but I am inclined to think that we will, because the average temperature in the heating flues at Walkerville was around 1800°F. only with 2100°F. as the hottest spot and such a temperature can be easily increased without danger.

Fuel Required by the Oven

During the five periods of run related the fuel consumption per ton of coal was as follows:

Run A	7,814,000	B.t.u.
" B	2,533,000	"
" C	5,184,000	"
" D	3,465,000	"
" E	2,560,000	"

The enormous consumption of run "A" comes mainly from a badly regulated combustion with burners that were not located the proper way, at a time when the mechanical features of the oven attracted our attention more than anything else.

The low consumption of run "B" is directly a reaction to the high consumption of run "A." We had the burners changed and we did our best to reduce consumption as much as we could; hence the

result of 2,533,000 B.t.u. of fuel per ton of coal distilled. The gas used was a 540 B.t.u. coke oven gas.

In run "C" we were trying to adjust other features and paid less attention to the burners. Their location on top of the ovens was not good and it was painful to attend to them in winter time.

In run "D," the first run of the Walkerville oven, we were again busy with the mechanical features and did not look so much after the burners, hence a higher consumption; but in run "E" we regulated them more closely and got the consumption down again near to 2,500,000 B.t.u. per ton of coal. The last two runs were made with 150 B.t.u. producer gas as fuel, having necessarily a lower efficiency than coke oven gas, so that a consumption of 2,560,000 B.t.u. in run "E" shows really a better efficiency in heat utilization than in run "C."

This is a fuel consumption somewhat higher than that obtained in high temperature ovens. Theoretically, it is not satisfactory. The coke and distillation products come out of the oven at lower temperature than in the case of high temperature ovens, carrying less heat away, and the oven is never opened, while high temperature ovens remain wide open during the pushing of the coke; therefore our fuel consumption should be lower.

We base our fuel consumption for the Italian oven on the obtained results, that is 2,500,000 B.t.u. per ton of coal, but we expect to be able to bring it down materially.

The following figures show us good possibilities in that line. When the Walkerville oven was running, say 40 tons of coal a day, its fuel consumption was about 100,000,000 B.t.u. per 24 hours. While not running it required about 50,000,000 B.t.u. to keep it at temperature. Therefore we needed half of that heat for the distillation while the other half was the compensation for radiation. Of course, of these amounts a certain proportion was going to the stack.

The heating system was giving about 20% stack losses and the distribution of heat was roughly as follows:

Stack	20% or	500,000 B.t.u. per ton of coal distilled.
Radiation	40% or	1,000,000 B.t.u. per ton of coal distilled.
Distillation	40% or	1,000,000 B.t.u. per ton of coal distilled.

Now if we succeed in cutting down radiation losses in two, we will have the following heat distribution:

Distillation	53% or	2,000,000 B.t.u. per ton of coal distilled.
Radiation	27% or	500,000 B.t.u. per ton of coal distilled.
Stack	20% or	360,000 B.t.u. per ton of coal distilled.

and the oven will be running with a fuel consumption of 1,860,000 B.t.u. per ton of coal.

Heating System

Evidently the heating system of any oven must be adjusted with the methods of distillation used. Once a method of distillation has been chosen a practical heating system must be applied to it. This is much more difficult than it seems at first view. Proof of this assertion is the fact that progress is still being made in the heating system of the old high temperature oven and that this progress together with the increased production derived is a good part of the success of our best coke oven builders.

On the basis of the experience gained with the Ford ovens we think the heating system of the Italian oven will be a good step ahead, but it is too early to speak of that now and we will wait for results first.

Gas and Light Oil

The gas production per ton of coal was as follows:

Run A 5,066 cu. ft., 30% Nitrogen, 616 B.t.u.
Run B 3,821 cu. ft., 40% Nitrogen, 526 B.t.u.
Run C 3,565 cu. ft., 13% Nitrogen, 860 B.t.u.
Run D 4,487 cu. ft., 15% Nitrogen, 790 B.t.u.
Run E 3,973 cu. ft., 15% Nitrogen, 790 B.t.u.

The large volume of gas in Run "A" comes certainly from a large amount of air introduced in the oven. The amount of nitrogen in the gas shows it clearly. Probably that amount in Run "A" was much higher than indicated and the amount of B.t.u. lower, few gas analyses having been made during that run.

We have good indications that the age of the coal (I mean the length of time the coal has been lying on the yard) has much to do with the amount and quality of gas and tar.

In run "E" with freshly received coal, we have, per ton

1st week 3,700 cu. ft. with 881 B.t.u. per cu. ft.

2nd week 3,822 cu. ft. with 804 B.t.u. per cu. ft.

At the end of this second week we started to receive a coal that had been lying on the yard all winter. It gave per ton

3rd week 4,425 cu. ft. with 713 B.t.u. per cu. ft.

After that we had a mixture of both old and fresh coal of unknown proportion.

The weathering of the coal did not seem to affect greatly the amount of heat in the gas, per ton of coal. It gives only a greater volume of a poorer gas.

It is difficult for us to say what percentage of light oil was taken out of the gas because sometime we were scrubbing the gas and sometime not.

As far as we can see it seems that the amount of light oil in the gas that can be recovered with absorbing oil at temperatures of

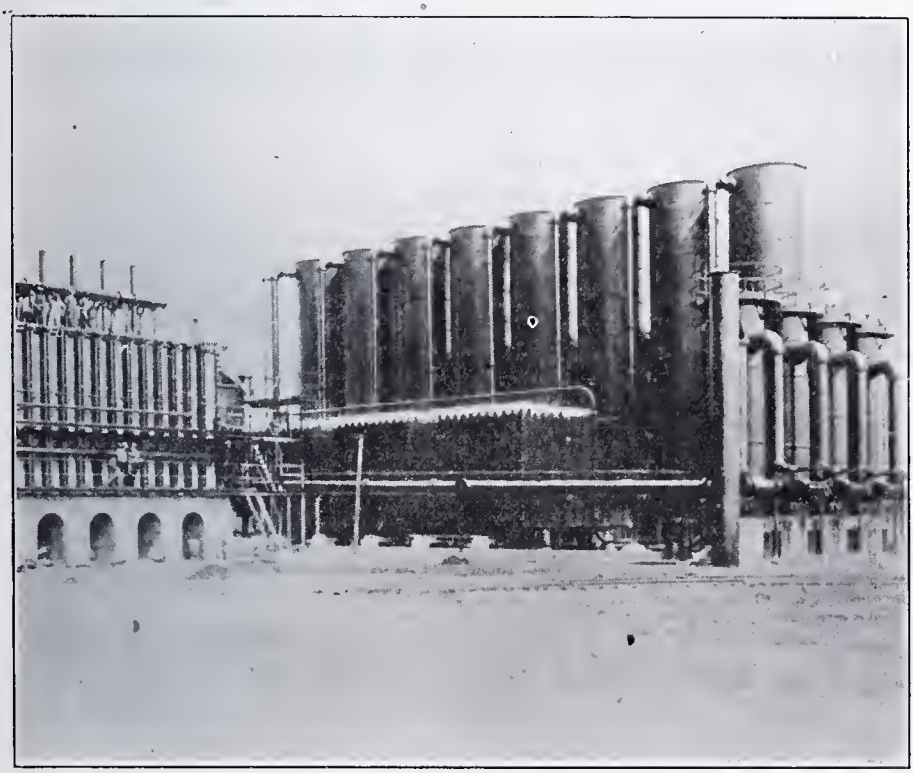

FIG. 5. GENERAL VIEW OF WALKERVILLE, ONT., RETORT
Showing gas coolers, condensers and scrubbers

70°-75° F., after the gas has been cooled down to that temperature, is about 2 gallons per ton of coal.

We might say that our gas gives us, per ton of coal, 3,300,000 B.t.u. without scrubbing, and 3,000,000 B.t.u. after scrubbing, the difference of 300,000 B.t.u. representing the light oil.

The quality of the gas was not always what it should have been. We have had runs of one day or even longer during which the gas was registering between 900 and 1000 B.t.u. without coming lower than 900. Other days it was coming down from time to time because of lack of regularity in the operation. Improper feeding due to tramp iron in the feeder was probably the most frequent cause of these irregularities, but as we said, we are taking care of that and other causes in the Italian oven. We can easily keep our gas up to the following composition:

CO_2	Vol. % 5.5	CO	Vol. % 6.
C_nH_m	Vol. % 6.	H_2	Vol. % 15.
C_2H_4	Vol. % 7.	CH_4	Vol. % 53.
O_2	Vol. % .5	N_2	Vol. % 7.

As for the light oil in the gas, we know little concerning its quality. Probably it is similar to the quality of the lighter fraction found in the tar.

TAR AND AMMONIA

The tar is certainly the largest part of the by-products of low temperature distillation of coal.

The amount of tar was recorded in the last test only because the amount of coal we were distilling was small as compared with the size of the by-product plants and it took quite a time before the circuits filled up.

At the beginning, at the Rouge plant, we thought we had only 17 gallons of tar per ton of coal. With the filling up of the system, that amount kept increasing from run to run. The last run showed 23 gallons.

At Walkerville, the tar was recorded during the last run only (Run "E"). It gave:

1st week 29.3 gal. per ton of coal
2nd week 29.2 gal. per ton of coal
3rd week 22.4 gal. per ton of coal
4th week 20. gal. per ton of coal

Same remark here as to the amount of gas: the first two weeks we were distilling fresh coal, then came the weathered coal. It seems that the coal we had, when absolutely fresh and under the condition of the oven, should give around 30 gal. per ton, while weathered, that coal would give only about 20 gal.

The amount of ammonia was small, about 2 lbs. per ton of coal.

As for the amount of ammonia water, we have not been able to determine it, because we were using some steam in the screw conveyor bringing the coke from the oven to the elevator of the power station to prevent ignition and a good part of that steam was going back to the oven. In our estimation the amount of water formed by the coal, outside of the moisture it contains, may be around 3%, but that needs confirmation.

The quality of the tar has been tested by Professor Allen Rogers, who has found in his samples a distillate of 50.5% which gave the following by fractional distillation after removal of the tar acids.

From 94° C. to 210° C.....51.5%
Higher 48.5%

The tar acids and pyridine bases of our tar have been studied by Robert M. Crawford, who presents a supplement to this paper. The tar analized by Mr. Crawford gave somewhat different results, but such differences in quality of tar must be expected as long as the development stage is not completely over.

The tar products are important from a commercial standpoint because in the present stage of low temperature distillation we cannot afford to neglect anything to make it pay.

An important remark is that at the beginning, at the River Rouge plant, our tar did not settle very well, probably because of air leaking into the distillation chamber and partial oxidation of the hydrocarbons, while at Walkerville we had a tar which separated perfectly from water and retained no more than 2% of moisture.

COKE

Little needs to be said about our coke. It comes in light sheets partially broken when they pass through the discharge of the oven. These sheets are very porous and their specific gravity, before being broken, is around 0.16; broken as they are coming out of the oven the specific gravity is about 0.2. They are very friable,

easy to crush and pulverize. Coal pulverizers fed with this coke have shown an increased output. This coke does not seem to be more abrasive than ordinary coal.

Our coke contains, as we have seen before, from 15% to 7% volatile. A well regulated production would probably give about 10%, as there is no apparent advantage in taking time to distill further than that.

BALANCE OF THE PRODUCTS

In order to follow our operation and see what we were losing, we have made the balance of the products obtained as carefully as we could. That balance applies to 24 days of continuous run, at Walkerville, and shows the following average per ton of coal.

In Weight:

Tar, 26 gal. @ lb. 9.2 per gal.	lb.	239
Gas, 3,973 cu. ft. (16 cu. ft. to the lb.)	lb.	250
Ammonia Water	lb.	60
Coke	lb.	1,425
Total products from 2000 lb. of coal	lb.	1,974
Loss, per ton of coal	lb.	26

In Heat Units:

Coke, 1,425 lbs. @ 12,800 B.t.u.	18,240,000	B.t.u.
Tar, 26 gal. @ 160,000 B.t.u.	4,160,000	B.t.u.
Gas, 3,973 cu. ft. @ 793 B.t.u.	3,150,000	B.t.u.
Total in products	25,550,000	B.t.u.
Out of 2,000 lbs. of coal @ 13,500 B.t.u.	27,000,000	B.t.u.
Loss	1,450,000	B.t.u.

Evidently the heat loss is too great—the exothermic heat of distillation of a coal of that quality is much lower. As compared to that the loss in weight is much smaller.

The only way we can account for that difference is that some air finds its way into the oven and there its oxygen combines mainly with the hydrogen, showing little loss in weight as compared with the loss in B.t.u.

Another reason that makes us think so is that there is no corresponding increase in carbon mono and dioxide when we have an increase in nitrogen in the gas.

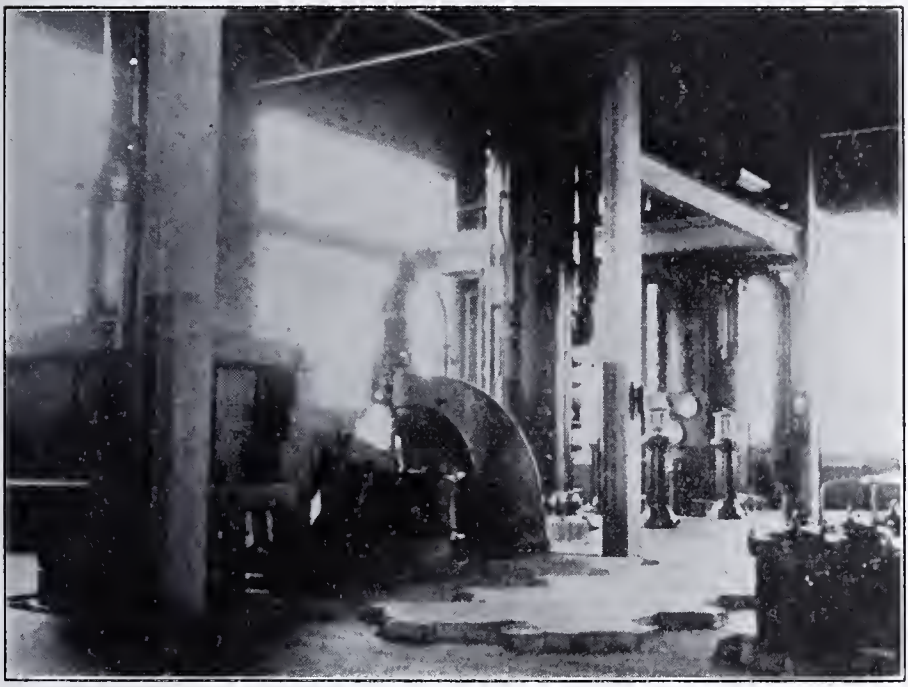

FIG. 6. INTERIOR VIEW OF BY-PRODUCT HOUSE
Showing ammonia saturator at the right, sulfate centrifuge at center, light oil still at rear and continuous washers extreme right.

Losses are due to leakages, these leakages working both ways, by letting gas and vapors escape when the pressure in the oven is too high and by letting air come inside the distillation chamber and burn part of the products when the pressure is too low.

Means of close regulation and tightness of the distillation chamber are important necessities. We have very much improved our oven with respect to these conditions during our work on the Ford ovens and we expect the Italian oven will give complete satisfaction.

SUPPLEMENT
CHARACTERISTICS OF PIRON LOW TEMPERATURE TAR

By ROBERT M. CRAWFORD

The following data were derived from an examination of two five-gallon representative samples of Piron low temperature tar taken from several thousand gallons of tar in storage at the Piron Walkerville Unit of the Ford Motor Company in June, 1926.

The entire samples were distilled in a small steel experimental still with the following results:

Water	2.5%	by	vol.
Over at 170°C.	3.3	"	"
" " 190°C.	4.4	"	"
" " 200°C.	7.8	"	"
" " 210°C.	10.2	"	"
" " 220°C.	13.8	"	"
" " 230°C.	17.0	"	"
" " 240°C.	19.4	"	"
" " 300°C.	25.1	"	"
" " 350°C.	34.0	"	"
Pitch	66.0	"	" M.P.—150°C.

The total oil distillate when extracted with 10% caustic soda solution yielded 30% by volume of free phenols; liberated with dilute sulfuric acid. The residual oil when extracted with dilute sulfuric acid yielded 5% by volume of free, dried pyridine bases; liberated with slaked lime. The final residual oil when distilled yielded the following results:

First drop	92°C.		
Over at 120°C.	0.4%	by	vol.
" " 130°C.	0.6	"	"
" " 140°C.	0.8	"	"
" " 150°C.	1.4	"	"
" " 160°C.	4.3	"	"
" " 170°C.	9.9	"	"
" " 180°C.	14.0	"	"
" " 190°C.	18.4	"	"
" " 200°C.	22.8	"	"
" " 210°C.	28.0	"	"
" " 220°C.	32.8	"	"
" " 230°C.	38.0	"	"
" " 240°C.	43.8	"	"
" " 250°C.	52.6	"	"
" " 260°C.	60.0	"	"
" " 270°C.	66.8	"	"
" " 280°C.	72.4	"	"
" " 290°C.	77.5	"	"
" " 300°C.	85.0	"	"
Residue and Loss	15.0	"	"

Unsaturated compounds in the neutral oil roughly determined by treatment with 95% sulfuric acid amounted to 79%.

The crude phenols when fractionated in a preliminary distillation:

Water	10.6%	by vol.
Below 187°C.	1.6	" "
187-205°C.	44.5	" "
205-210°C.	1.1	" "
210-225°C.	1.9	" "
225-230°C.	.2	" "

It is interesting to notice the predominance of phenols boiling within the cresol range.

A further quantity of the crude phenols fractionated to determine the quantity of recoverable commercial grades of phenols gave:

Phenol	Trace	
Cresylic Acid (185-230°C.)	63.7%	by vol.
Higher Acids (230-320°C.)	16.0	" "
Residue and Loss	20.3	" "

When subjected to redistillation the cresylic acid yielded about 30% by volume of cresols conforming to the U.S.P. Specifications.

The following is a summary estimate of tar products per ton of coal distilled (30 gal. tar/ton coal):

98% Cresylic Acid	1.95	gal.
High Boiling Tar Acids	0.49	"
Crude Pyridine Bases	0.50	"
Neutral Oil	6.50	"
Pitch	20.0	"

No investigation as to the constitution of the neutral oil was made beyond the distillation test and washing with 95% sulfuric acid, but it appears that a considerable portion of the oil can be made directly into motor fuel by simple distillation, and it is possible that by cracking a considerable portion of the balance can also be taken to motor fuel. The neutral oil and its distillate up to 240°C. is characterized by being extremely mobile, purple in color and having a noticeable "bloom." The distillate above 240°C. was yellow in color and quite mobile.

The following can be considered an average over-all estimate of recoverable products of known commercial value from one ton of

high volatile coal distilled by the Piron Process as operated by the Ford Motor Company:

Coke	1,460 lb. (10% volatile)
Gas	4,000 cu. ft. (750 Btu./cu. ft.)
Ammonia	2 lb.
Motor Fuel from gas	2 gal.
Motor Fuel from tar	2 "
98% Cresylic Acid (Pale)	1.95 "
High Boiling Acids (Pale)	0.49 "
Neutral Oil	4.5 "
Hard Pitch	200 lb.

In deriving the above figures no credit has been taken for pyridine bases or a possible increase of motor fuel yield by cracking the neutral oil. It has been remarked, by parties who have seen the neutral oil, that it may have considerable value as a flotation oil on account of its frothing characteristics.

The ash content of the free carbon in the tar was quite high, its presence being probably due to coke dust drawn into the tar. The gas off-take was located at the coke discharge and where coke dust could easily contaminate the tar. This condition undoubtedly accounts, also, for the high pitch yield of Piron tar.

In the interests of the Ford Motor Company the writer estimated that a tar refining plant handling 6,000 gallons of this tar per day would yield a net revenue of nearly $2.00 per ton of coal. This estimate was based upon recovering 98% cresylic acid, high boiling acids and neutral oil for sale and upon flaking the pitch to be returned to the oven to be coked along with the raw coal. In making this estimate the following prices were assumed:

98% Pale Cresylic Acid	60c/gal.
High Boiling Acids	70c/gal.
Neutral Oil	20c/gal.
Hard Pitch	$5.00/ton
Coal	$5.00/ton

THE LOW TEMPERATURE DISTILLATION OF COAL IN ROTARY RETORTS

By W. A. Darrah
Continental Industrial Engineers, Inc.

General

The belief that the direct consumption of fuel high in volatile, such as many bituminous coals, is uneconomical is rapidly gaining ground. As a result of this opinion, which appears to be well founded, much attention is being given to the possibilities of economically removing a portion of the volatile materials from coal prior to burning.

There are, of course, many obvious advantages of such a procedure, the principal obstacles being the matter of practicability of a process and the economic balance sheet which any given process shows.

The object of this discussion is to describe and show briefly some coal distillation apparatus which has been tested out and the products which result.

Process

The process to be described is based largely on that known as the Thyssen process and carried to a rather high degree of development in Germany. The process uses practically any form of coal, but screenings or slack coal appear to be most desirable for reasons which will be discussed later.

The steps as they are followed out consist in first drying the coal and then feeding at a uniform controllable rate into the cool end of a rotating drum. The drum is provided with an internal spiral flange which extends substantially from end to end. As the drum, which is substantially horizontal, rotates, the small particles of coal, of course, remain at the lower portion of the drum and are gradually tumbled over and over each other. As the particles of coal continually fall to the bottom of the drum the spiral flange forces them progressively from the entering end to the leaving end of the drum. The drum is heated around its outside to a

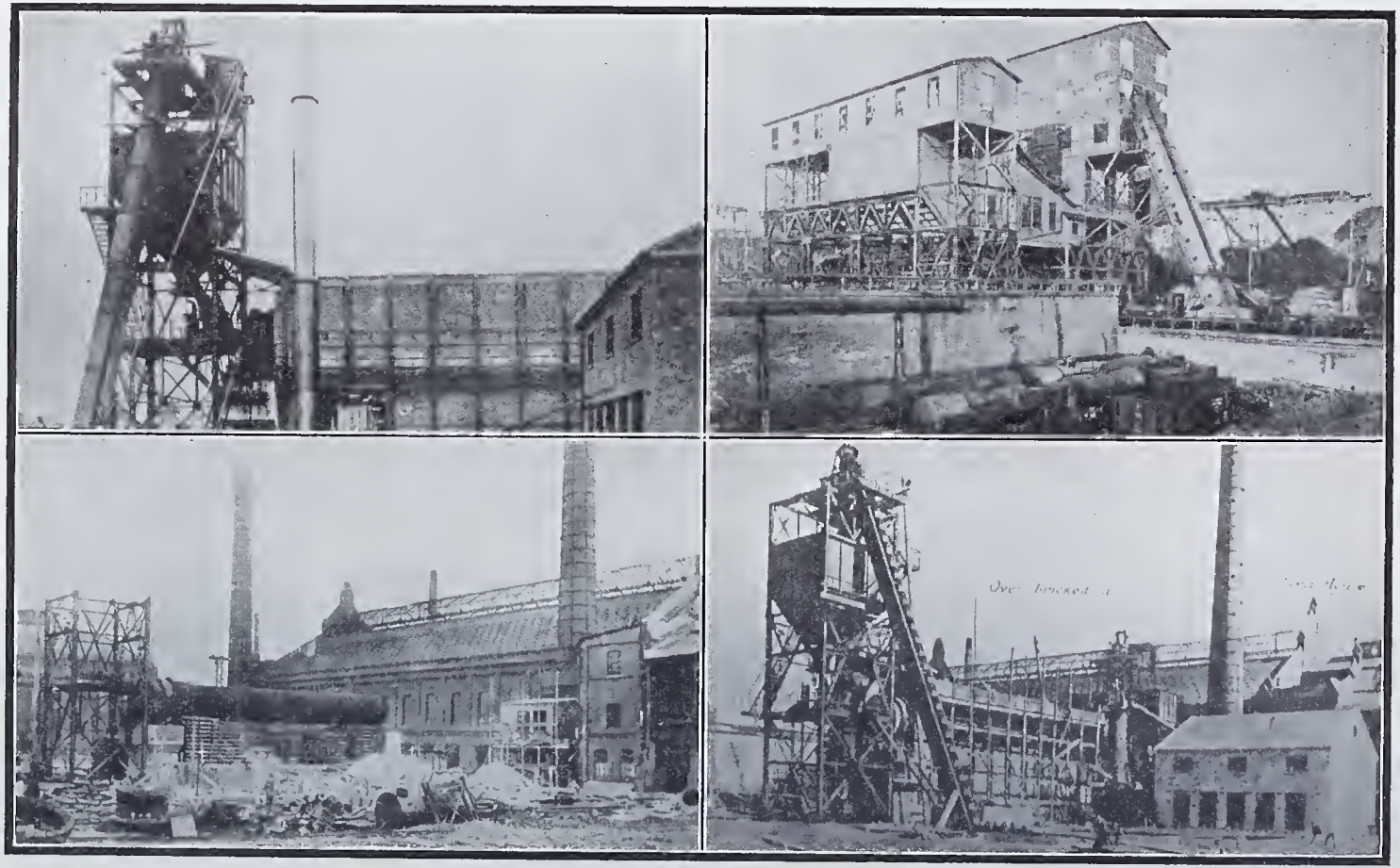

FIG. 1. VIEWS OF GERMAN PLANTS
Completed and under construction

temperature ranging from 550°C. at the discharge end to about 450°C. at the feed end, thus subjecting the coal to a gradually increasing temperature treatment. As the coal travels forward it softens under the influence of heat giving off some volatile materials and becoming plastic or sticky. The coal does not appear to adhere to the drum itself or steel work attached to it, probably owing to the fact that the drum is at a higher temperature than the coal and, therefore, has a tendency to soften or melt the binder of any coal which adheres to its surface.

The lifting and dropping of the coal particles, however, has a tendency to cause them to cement or stick together somewhat in the manner as a snow ball will form when a lump of snow is rolled over the ground covered with a wet sticky snow. Not all of the particles of coal adhere, experience indicating that from 50 to 75% (depending, of course, entirely on the nature of the coal treated) forms into large lumps while the balance is found in the form of particles ranging from one half inch down to one eighth inch or less. There is practically no dust in the sense of very fine light particles.

The volatile material which is given off as the coal progresses through the drum travels down the central portion of the drum in such a manner that the major portion of it does not come into contact with the hot walls of the drum. This construction will be described in more detail in connection with the apparatus itself. The arrangement which has been worked out has for its object, of course, the rapid removal of the volatile material from the coal without bringing the material into contact with the hot surfaces of the drum which would cause cracking of the volatile materials, thus giving an excessive amount of gas and a minimum amount of liquid products.

As the volatile materials leave the drum they are separated from the solid materials and pass through a dust collector where as much of the dust as possible is precipitated. The volatile materials thus freed from dust consist largely of water, tar, oil and gas. The tar and a portion of the oil is condensed in a scrubber which we have found gives excellent results when of the spray type. Sprays are obtained by the splash method rather than by nozzles. The condensation of the tar and a portion of the oil and water is obtained by causing the volatile materials to travel upward through a steel

tank approximately 20′0″ long while subjected to the downward travel of the large body of small drops and spray of the same condensed tar. The mixture of recirculated tar and condensed tar, water and oil is allowed to settle in a storage tank from which it is repumped continuously to the scrubber. The excess is drawn off periodically to the proper storage tanks.

In the case of the installation now operating we have provided a second condenser of the steel tube type operated at a lower temperature than the tar washer and arranged to make a second cut of the volatile oil. The volatile materials which do not condense in the tube condenser continue through the mains to the motor driven exhauster and are then delivered to the burners at various points around the plant where the gas is used for fuel.

Apparatus

The apparatus employed to carry out the process which is described above is shown in the illustrations. The plant illustrated is a small semi-commercial unit erected at Clearing, Illinois, with a view of working out the various technical and economic problems involved in a process of this kind. The plant has been constructed with a view of including only the absolute essentials for demonstrating this process and no unnecessary equipment has been included.

The process starts with a small dryer located adjacent to the elevator which feeds the storage hopper. Coal which has been stored under normal dry conditions and not subjected to water or moisture either in processing or due to weather conditions can normally be handled without additional drying although obviously the capacity of the equipment is somewhat increased and the ease of handling improved by drying. The practical limitations which we find on the moisture content are imposed by the feeding and handling mechanism rather than by the conditions in the rotary drum.

From the storage hopper the coal passes directly to the center of a rotary feeding table and the constant cut is taken off from the outside of the table giving a relatively uniform feeding rate.

As the coal leaves the feeding table it falls downward to an intermittent bucket type feeder rotating about a horizontal axis. This feeder serves both as a seal to prevent the egress or ingress of gases and, at the same time, controls the quantity of coal which

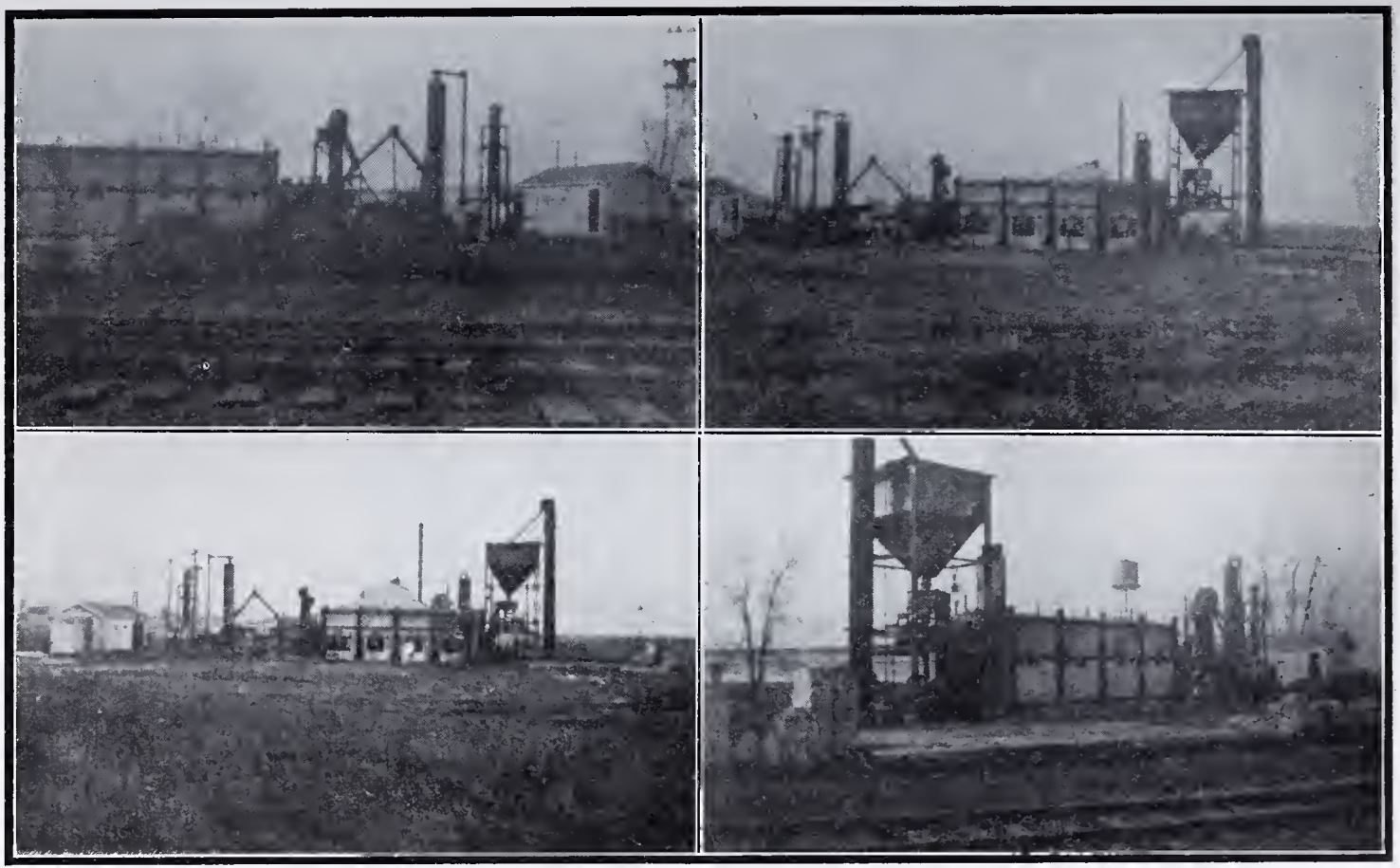

FIG. 2. VIEWS OF COMPLETED AMERICAN PLANT—CLEARING, ILLINOIS

is delivered at any given instant. From the seal type intermittent feeder the coal falls down an inclined chute into the entrance of the rotary drum. All of this equipment including the joint between the inclined feeding chute and the drum is maintained as tight as practical manufacturing and operating conditions for this class of machinery will permit, for the obvious reason that the entrance of air into the drum will cause the partial combustion of products which should be saved and also, of course, adds to the possibility of fires or fire hazard. On the other hand, the passage of the gases outward represents loss, troublesome condenser deposit and the hazard of fire as well as discomfort to the operators. No difficulties have been encountered in maintaining these joints sufficiently tight over long periods.

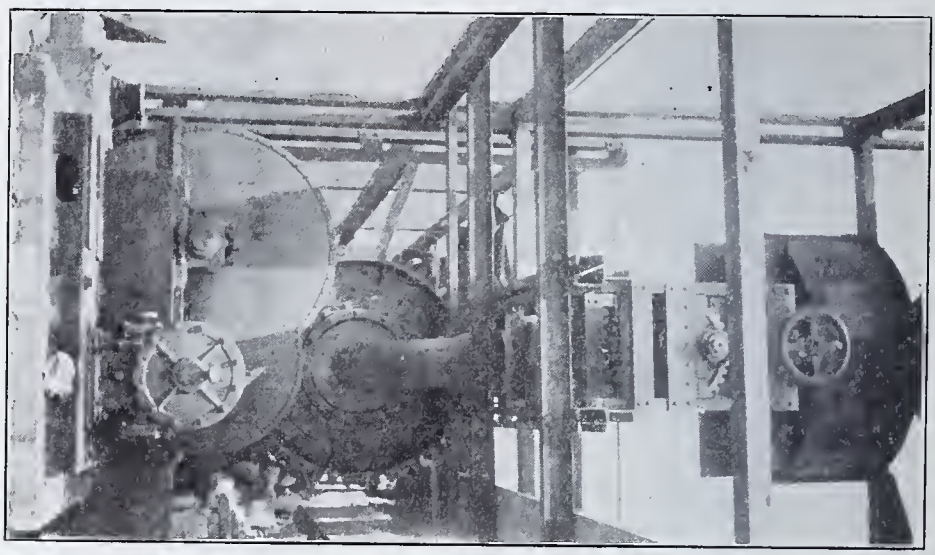

Fig. 3. Detail View of American Plant
Under construction

The retort consists of the horizontal cylinder provided with internal flanges arranged in a continuous spiral so that the coal which enters the retort is caused to gradually travel forward and discharge at the far end. The drum is constructed of steel approximately 1½" in thickness and amply reinforced. The drum rotates about its horizontal axis continuously at a rate of about 4 R.P.M. The supports for the drum are at each end just outside of the oven which supplies the heat.

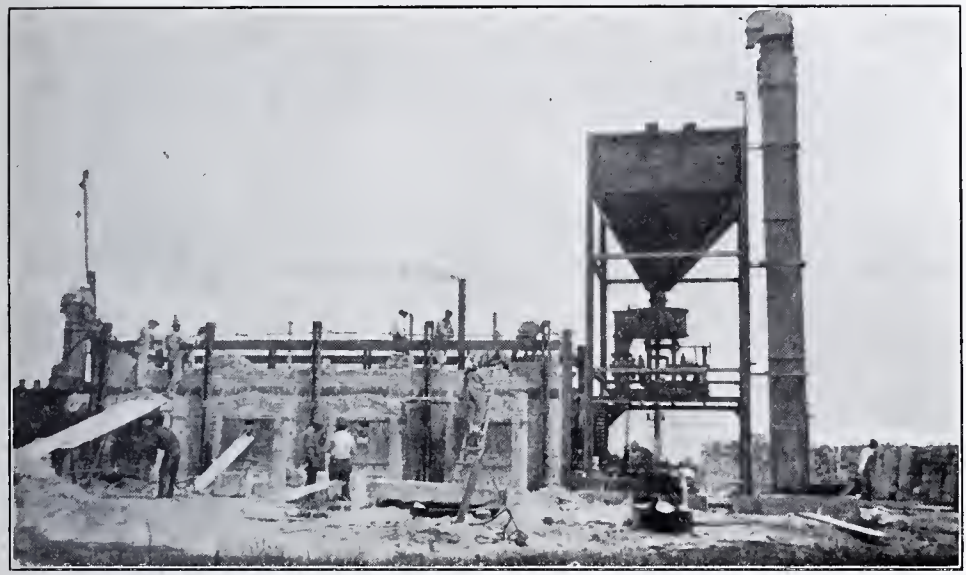

Fig. 4

Fig. 5. Detail Views of American Plant

The coal in traveling through the drum occupies a band along the bottom which represents approximately 90° of the total circumference when the drum is normally loaded.

The rotating retort is inclosed entirely, except at its two ends, in a substantial fire brick heating furnace which is fired from a series of dutch ovens in such a way as to maintain a uniform heat distribution without excessive hot or cold spots. The individual fire boxes are arranged at intervals along the length of the retort, so that the effect of graduating the temperature from one end of the retort to the other can be secured by the manipulation of the individual fire boxes.

In the interior of the rotary drum a central tube is placed in such a manner as to conduct the volatile materials given off by the coal without bringing them into contact with the walls of the drum. This effect is obtained by a series of slats arranged to form the tube portion in a section of the drum in which the volatile materials are given off. Beyond this portion a solid central tube is employed.

The low temperature coke or semi-coke as it has been called is discharged from the hot end of the rotary drum through a short vertical pipe into a rotary feeder, the general construction of equipment being substantially similar to the feeders employed at the charging end of the drum.

The dust collector which we have used to advantage is placed adjacent to the discharge end of the drum, but connects to the central tube. The dust collector as it has been constructed consists of a series of chains hanging closely adjacent to each other and thus forcing the gas to travel through a large number of very small openings. The gas travels downward and then upward making a 180° bent in passing around a baffle in the dust collector. In operation we find that the dust deposits on the links and chains and forms its own filtering medium to a large extent.

Provision has been made for agitating the chains during clean-up periods causing the dust to fall to the bottom where it is drawn out through a chute provided for this purpose.

From the dust collector the gas passes to a vertical splash type spray scrubber which has been previously described. After receiving the proper scrubbing the volatiles are then condensed in a Griscom-Russell tube condenser arranged to have the cooling water

on the outside of the tubes and the gases on the interior of the tubes. This condenser has been arranged so that the circulating volatile materials make a loop pass upward and then downward through the condenser, thus maintaining each pass to secure two cuts of varying gravity with the same equipment.

Centrifugal pumps are used for circulating the tar through the scrubber while a positive pressure Connersville type exhauster is used for moving the gases.

In addition to the photographs showing in detail the American plant several of the photographs attached hereto show plants recently put in operation in Germany.

PRODUCTS

As in any other process based upon the use of natural raw material the character and quantity of the products produced will vary over a wide range depending upon the nature of coal on which the operation is based.

In the writer's opinion, the operation is likely to be most successful when using a bituminous coal having some coking characteristics and a large amount of volatiles. Under these conditions the process produces a high grade smokeless fuel very well suited for domestic purposes, a very rich gas and considerable oily tar. Small amounts of ammonia and phenol may be obtained, but their presence is not as marked as in the case of the present high temperature process.

In order to give a brief idea as to the nature and quantities of the products produced a description will be given of the results obtained using an Eastern Kentucky bituminous coal having an analysis as shown below.

Moisture	1.76%
Ash	3.71%
Fixed Carbon	60.56%
Volatile	33.97%
Sulphur	.58%
Com'cial B.t.u.	14372

DRY

Ash	3.78%
Fixed Carbon	61.64%

Volatile	34.58%
Sulphur	.59%
B.t.u.	14629

Coke

The coke obtained from the above coal ranges from 65 to 70% by weight of the dry coal which enters the drum. Obviously the weight of the coke will be considerably influenced by the temperature conditions to which it is submitted, and considering the process as a whole and the marketability of all of the various by-products it would appear that with the coal whose analysis is given above the temperature range should be a substantially uniform gradient from 450°C., at the entering end to 550°C. at the leaving end.

Under these conditions a light but reasonably strong and freely combustible coke is obtained showing an analysis substantially as given below.

Water	1.85%
Volatile Matter	6.89%
Fixed Carbon	83.32%
Ash	7.94
Sulphur	.50%
British Thermal Units per lb. as received	13670
British Thermal Units per lb. Dry	13927

Between one-half and two-thirds of the coke produced leaves the drum in the form of lumps ranging from three-quarters of an inch up to 4" in diameter. The balance is in the form of smaller particles ranging from one-half inch down.

Our investigations indicate that this coke is a very desirable fuel for domestic purposes in that it ignites readily, responds quickly to the draft circulation, burns without smoke or soot and gives a low powdery ash. On being ignited the coke burns with a bright blue flame which changes to a steady red glow as soon as the coke is heated throughout. In almost every respect this fuel is much more satisfactory than the varieties of high temperature coke usually encountered. The weight of this coke is 30 to 40 pounds per cubic foot when loosely placed in a container. The strength is somewhat less than that of the usual forms of high temperature coke, but appears ample for shipping and handling. Briquettes

have been made by pulverizing the smaller pieces of coke and these have very desirable characteristics as an anthracite substitute, being nearly smokeless, but easier to handle than anthracite. It will, of course, be obvious that the remaining volatile material left in the coke together with the more open structure give the desirable characteristics which distinguish low temperature coke from high temperature coke.

TARS AND OILS

In addition to the quantities of coke described above the yield of tar ranging from 25 to 40 gallons per ton results from the distillation.

The tar as collected in the scrubber is liquid black and sticky with a very strong odor of phenols.

An average analysis of the total tar output is given below.

Water		7.70%
Specific Gravity at 60°F		1.118
Distillation—Boiling point		93°C.
Distillation at	175°C.	2.96%
"	185°C.	3.94%
"	200°C.	14.60%
"	205°C.	17.70%
"	215°C.	23.60%
"	225°C.	27.60%
"	235°C.	31.50%
"	245°C.	33.50%
"	255°C.	25.50%
"	265°C.	37.40%
"	275°C.	39.40%
"	285°C.	42.40%
"	295°C.	44.30%
"	300°C.	45.30%
"	305°C.	47.70%
"	315°C.	49.60%
"	325°C.	51.60%
"	335°C.	53.60%
"	345°C.	57.50%
"	355°C.	59.40%
Residue above	355°C.	38.90%

Coke Residue	17.62%
Sulphonation Residue	1.79%
Tar Acids	23.00%

As seems to be well recognized, the low temperature tar produced by this process is low in naphthalene and anthracene. Simple phenol (carbolic acid) seems to be present to the extent of about one to two percent, but the higher phenols are present in relatively large amounts, as will be noted from the analysis. There is a small quantity of unsaturated hydrocarbon present in this tar. This shows itself by the very great readiness of the tar to oxidize. Spread out in a thin layer it will eventually dry into a paint-like consistency, but without the addition of other materials it would appear to make a very unsatisfactory paint.

The tar can be separated into oils such as creosote oil, flotation oil, etc., which have a very widely established and rapidly growing market. This has been carried out to some extent and seems feasible. It appears desirable to remove as far as possible the amount of water in the tar prior to commercial distillation.

The cuts of oil distilled from the tar below 250°F. come either colorless or a light lemon yellow, but have a peculiar property of very quickly turning dark brown or black when exposed to the air, apparently due to oxidation. The color changes during the oxidation somewhat resemble those noted in the oxidation of phenols.

Gas

The amount of gas obtained from distillation naturally depends on the nature of the coal and the temperature. From 3000 to 4000 cubic feet of gas per hour represent the normal production with the grade of coal discussed above. The gas will average over 1000 B.t.u. per cubic foot and contains a relatively large amount of unsaturated hydrocarbons. Up to the present very little time has been devoted to the commercial application of the gas for any other purpose than the direct use of it for fuel. Near any industrial center there is no question but what the entire production of gas could be very readily absorbed at a decided profit both to the producer and purchaser.

Application

The above discussion gives an outline of some of the results obtained by the distillation of coal in a horizontal rotary drum.

The process is unquestionably operative from a technical standpoint and the equipment is available for carrying on the process with a reasonable maintenance and at a reasonable expense.

The economic situation at present appears to be satisfactory for the profitable operation of plants of this kind in many localities in the United States providing proper coal is used as a basis for the process.

It would seem reasonable to expect that the next few years will see great activity along this line with a view of assisting in the transformation of the coal industry into a stabilized profitable business for both the owners and the workers.

DISCUSSION

YOSHIKIYO OSHIMA.* As a contribution to the discussion at this session I wish to present the following paper.

LOW TEMPERATURE COAL CARBONIZATION IN JAPAN

The low temperature coal carbonization is a very young industry in Japan, but there are already five works in actual operation. They carbonize, in total, over 300 tons daily. Among them the following will be worth describing:

1. CYLINDER RETORT AT OSAKA GAS WORKS, OSAKA

This is a patented process of Dr. Shimomura, and the object of this process, as already reported some years ago in the Journal of the Society of Chemical Industry, London, is to prepare a blending material for making a good metallurgical coke.

Two cylindrical retorts are laid horizontally and parallel, one on the other. Each retort has an agitator which rotates about 1 to 3 times per minute according to the nature of coal to be treated. The coal is charged from one end of the upper retor and is moved by means of the agitator to another end, then down to the lower retort through a connecting chamber. The carbonized product is drawn out through a cooler in which a screw conveyor drives it outside. The retorts are set in a furnace and externally heated with town gas, the heating value of which is about 480 B.t.u. The gas from these retorts is drawn out

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through a condenser, cooler and exhauster, and is then mixed with that from ordinary coal gas retorts.

The capacity of one bench varies naturally according to the nature of the coal and requirements of the products, the average being 200-300 kg. per hour, that is, 4-7 tons per day. The fuel consumption is about 26,000 cu. ft. Besides this, 18,000 cu. ft. of the same gas are used for driving the whole system.

The maximum temperature of carbonization is between 500 and 550° C. and the mean temperature at the point of connection of two retorts is about 330° C.

The latest result with Yubari coal is as follows:

Analysis of coal:

Vol. matter	42.86
Ash	8.28
Fixed carbon	48.86
Sulphur	0.30
Nitrogen	1.57
Heating value	7312 Cal. per Kg.

Analysis of semi-coke made:

Vol. matter	16.87
Ash	10.50
Fixed carbon	72.63
Sulphur	0.34
Nitrogen	1.86
Heating value	7190 Cal. per Kg.
Apparent sp. gr.	1.009
True sp. gr.	1.525
Porosity	34

Heating value of gas:

6,862 cal. per cbm. or 771 B.t.u. per cu. ft.

Analysis of tar:

Tar is collected at three different points.

	A	B	C
Specific gravity, 15 C.	0.985	0.962	0.950
Viscosity, Engler, 25 C.	3.8	2.0	1.8
Heating value, Cal./kg.	10146	10295	10645
Sulphur	0.34	0.50	0.69

Free carbon	0.19	0.01	0.03
Flashing point, C.	72	46	39

Analysis of gas liquor:

Ammonia content .....0.4 per cent

The yield of the products:

Semi-coke .....71.5 per cent
Tar .....10.0 per cent
Gas .....5230 cu. ft. per ton
Gas liquor ..... 5.8 per cent

Yubari coal is a good coking variety, but it does not give a compact metallurgical coke. It produces a fingery coke and is brittle. Semi-coke made by the process mentioned above is blended with raw coal and charged into a Semet-Solvay coke oven. The coke made is very good and satisfactorily meets every requirement of the market. Before this process was developed the company used to buy Chinese coal, but now this has been discontinued.

In regard to tar, they are making use of it in two ways: namely, cleaning of the gas main and carburation of water gas. A certain fraction of tar is injected into the gas main to take up the deposit of naphthalene and any other heavy products. The fraction between 200 and 300 is being used in place of gas oil and it shows very good results, both technically and commercially.

2. Iternal System at Hokoku Mine, Near Fukuoka

The Meiji Mining Company has been operating low temperature carbonization of coal on two systems for about three years. The one is both internally and externally heated, while the other is exclusively heated internally.

The retort of the first class has a small gas producer built in, and the gas produced there passes through the charge and gives its sensible heat to the coal in the retort. To accomplish external heating, carbonizing chambers and heating flues are arranged alternately, 10 chambers composing one bench. One isolated gas producer is attached to one bench and uses very poor quality of fuel, wash-off slack with over 70 per cent ash. The capacity of one bench is about 10 tons per day and it is worked on two shifts.

The fuel gasified in the built-in producer is a part of the semi-coke made in the chamber. The temperature can be easily controlled by regulating the quantity of fuel to be supplied to the producers.

In the internally heated system a gas producer and a retort are connected by an inclined chamber through which the producer gas proceeds into the vertical retort and gives its sensible heat to the charge. The charge of coal passes down through the retort continuously and drops into a cooler where the semi-coke is quenched *in situ* by steam injected from the bottom and also externally by water, while a part of it is introduced into the producer, without quenching, through the inclined connection. The semi-coke quenched is withdrawn by a chain conveyor and is separated into three grades by using a double sieve.

The producer gas is divided into two streams. The one goes up the retort through the inclined connection where coke is charged and the other passes through a canal into the lower part of the retort, just opposite the former. The temperature is controlled by adjusting the rate of formation of producer gas, that is, the rate of charging semi-coke into the producer, and by the damper located at the canal mentioned above.

The product of carbonizing varies naturally according to the coal and the temperature or the speed of the charge. It is very easily adjusted to meet the market requirements. The quality is very uniform.

The capacity of the retort now in operation is 8-10 tons per day according to coal treated, and they are carbonizing about 50 tons every day very successfully and economically. This retort was formerly designed to make a good domestic smokeless fuel, nothing but solid fuel. Now special attention is being paid to produce tar of certain specifications, as it has been found that tar can be used as a medium for coal dressing instead of oil. The tar is distilled and fractionated into three parts. The first is light oil and used in place of gasoline, and the last fraction is used as a binding material for making briquettes from semi-coke breeze.

The second fraction, between 200 and 200 C., after being treated properly, is used as a medium of coal dressing.

The results of operation are shown below:

Temperature Conditions of the Internally Heated Retort

	Winter	Summer
Blast	56	62
Ash zone of producer	..	120
Combustion zone of producer	..	980
Inlet of quenching chamber	350	390

Outlet of mixed gas	66	69
Outlet of fan	28	41

Analysis of semi-coke:

	Coal A	Coal B	Coal C
Moisture	4.91	3.68	4.03
Volatile matter	11.56	9.37	16.28
Fixed carbon	66.81	42.30	72.68
Ash	16.72	44.65	8.05
Sulphur	0.32	0.20	0.45
Heating value, Cal./kg.	6253	4009	7170

Carbonization degree at different points of the system:

	Top	Center	Bottom	Inclines	Prod. Top
Moisture	2.31	2.02	3.02	5.07	4.87
Vol. matter	38.75	22.57	15.46	7.93	5.97
Fixed carbon	45.08	63.45	68.01	70.36	73.34
Ash	13.86	11.95	13.51	16.64	15.82
Sulphur	0.43	0.42	0.48	0.40	0.35

Experimental Works

There are several experimental plants, among them two which are leading. The one is in the Imperial Fuel Research Institute, Tokio, and the other is being operated by the Navy Department.

The retort at the Institute is of a continuous vertical type. One bench is composed of 6 retorts, each with a capacity of 1.5 tons a day, making a total of 9 tons per day. The retort is made of ordinary cast iron in five sections and it is heated externally with producer gas. The complete result of operation with five different varieties of Sacchalin coal were published last year.

In the Institute, aluminum apparatus and the revolving kiln of Dr. Fischer are being usd as laboratory standards before coal is actually tested in the retorts. The Institute publishes all the records of laboratory tests of Japanese coals, and it is much appreciated by people who are designing or planning this sort of industry.

The Fuel Department of the Navy has two systems on a commercial scale, the one German Thyssen, with a rated capacity of 60 tons a day, and the other English Davidson, with a rated capacity of 20 tons per day. It is said they are both smoothly running.

Frank M. Gentry.* One of the greatest fields for low temperature carbonization of coal is in the production of a boiler fuel with simultaneous by-product recovery. In this field the smokeless characteristic of the semi-coke loses its significance, because our large central stations can burn any fuel without smoke. The application of low temperature carbonization to steam electric plants must therefore be entirely justified by the economies which it effects in the cost of power by virtue of extraction and sale of by-products. In recent years our great central stations have been adopting pulverized fuel in which certain advantages have been seen. If present tendencies continue in his direction, then we must consider the production of semi-coke suitable for firing as a pulverized fuel. We have three possible cases, pulverization of the fuel after low temperature carbonization, pulperization of the fuel between primary and secondary carbonization and pulverization of the fuel before carbonization. Most all processes can more or less lay claim to the first method. Of the several processes which may be classed in the method of preliminary pulverization, the McEwen-Runge Process has probably advanced the farthest at their full scale experimental plant at Lakeside.

As distinct from the pulverized coal low temperature carbonization processes of Newell and Sinnatt, as well as of White, who utilize radiation as the method of heat transfer, McEwen and Runge depend upon convection to transfer the heat from their recirculated hot gas to the coal particle. The transfer of heat by convection is a function of a power of the relative velocity of the fluid and the body. The laws of falling bodies in non-vortical fluids are well known and it is safe to conclude from them, even for a case of turbulent flow, that there are certain definite limits to heat transfer between a particle and a gaseous fluid in motion at certain gas velocities, due to the reduction to zero of the relative velocity of particle and fluid. This sets a maximum limiting velocity of gas circulation, which depends among other things on the size of the particles, density of the gas, etc., beyond which the efficiency of heat transfer is reduced and beyond which difficulties will be encountered with the gas carrying the pulverized coal out of the retort.

One very important aspect of low temperature carbonization in pulverized form is found in the fact that, both by convection and radiation, heat transfer depends directly upon the area of the absorbing body. Consequently, carbonization of small particles should and does effect an enormous reduction in the time of carbonization.

In the early days of low temperature carbonization the first attempts to develop a continuous process naturally led to an internal spiral conveyor. Most of these attempts utterly failed because the inventors could not prevent the charge from plugging the retort. Mr. Greene in the Greene-Laucks Process seems to have successfully surmounted this

*Assistant to the Consulting Engineer, The New York Edison Co.

difficulty and I dare say that provisions for heating the inner surface of the screw has a great deal to do with elimination of this trouble. In the Marshall-Easton Process, which also uses internal spiral conveyors, the problem has been solved in an ingenious mechanical way by providing a nest of interlocking spirals so that no rotary motion whatever is imparted to the charge, which moves only vertically through the retort.

Mr. Greene mentioned that the breeze from the process was mixed with the charge and returned to the retort. This is an excellent method of disposing of the breeze and has been used extensively in England with many well known advantages, particularly with high volatile non-coking coals, but it has the serious disadvantage of lowering the throughput of the retort and therefore the quantity of semi-coke produced per unit of investment.

The Thyssen Process described by Mr. Darrah has received a good deal of attention in Germany where several large scale retorts are said to have been in operation for several years. Rotary retorts, heated externally or internally, have certain well known advantages. In the first place they are continuous processes and avoid high maintenance, inevitably associated with any discontinuous process where the retort is periodically heated and cooled. Furthermore the rotary retort permits bulk treatment of the charge, which requires less handling and correspondingly lowers the cost of processing per unit throughput. The constant tumbling of the charge during carbonization assists heat transfer enormously by presenting fresh surfaces to the hot wall in the case of external heating and to the hot gas in the case of internal heating. As a consequence of this stirring up of the coke, heating is very uniform and likewise the volatile content of the semi-coke.

On the other hand there is great diversity in the size of the lumps of semi-coke produced. Some pieces are very large and must be broken, others are just right for domestic use and there is a relatively large amount of breeze which must be briquetted for the market. Many experimenters with rotary retorts, however, had a good deal of trouble with dust raised in the retort by the tumbling charge and carried over into the tar main by the gas. This reduced greatly the value of the tar and caused much trouble in the by-product plant. I have in mind one case in a rotary retort where even after the installation of special dust catchers 2 per cent. dust was carried over into the tar.

It seems that a great deal of trouble has been had in handling fusing coals in a rotary retort because they stick to the walls and build up a thick heat insulating layer. To avoid this difficulty, recourse has been had to various mechanical devices. Thus, Hutchins introduces a star-shaped breaker into his Fusion Process, which is an externally heated horizontal rotary retort, to chip the coke from the inner walls.

LOW TEMPERATURE CARBONIZATION OF COAL

By Fr. Mueller

Director, Low Carbonization Plant, Mathias Stinnes Mine, Essen, Germany

As is well known low temperature carbonization is understood to mean the dry distillation of solid fuels at temperatures of about 500° C.

In this process a maximum oil yield is obtained and at the same time a solid residual product which burns, however, with a long smokeless and sootless flame; this fuel is destined to have the most varied uses. It is, therefore, easy to understand that ever since the acquisition of this knowledge intensive works has been carried out looking to the commercial development of the process. The low temperature carbonization processes so far developed may be arranged in six classes which may be described in a few words as follows:

Group A: Processes with Indirect Heating

1. The coal is carbonized at rest in a batch process (for example the Coalite Process).
2. The coal is carbonized at rest in a continuous process (for example the Raffloer retort).
3. The coal is carbonized in motion in a continuous process (for example the KSG retort).

Group B: Processes with Direct Heating

1. The coal is carbonized at rest in a continuous process (for example in the canal retort).
2. The coal is carbonized in slow motion by a continuous process (for example the Lurgi process).
3. The coal is carbonized in more or less rapid motion in a continuous process (McEwen-Runge for example).

We may single out particularly those processes which carbonize the coal in motion and continuously (A3) because it is in this class processes have been worked out which have been most highly developed on the large scale and consequently offer the maximum certainty of com-

mercial operation. And we may also establish the relationships for carbonizing in rotary retorts especially as they have been tried out on the large scale in Germany. In determining the selection of the rotary retort several considerations of a general nature must be taken into account. In the first place the rotary retort permits continuous operation and the continuous feeding and agitation of the charge; secondly by its rotation the rotary retort continuously brings fresh particles of coal to the heating surface (the objection raised that in carbonizing with a rotary retort at most ⅓ to ¼ of the heating surface is being continuously utilized is, therefore, untenable); finally the rotary retort (kiln) is a type of equipment recognized as of the greatest steadiness of operation in the most varied industries so that from a technical point of view we need expect no great difficulties in this respect.

In Germany three types of large scale equipment have been developed for which the following considerations have been established:

(a) The horizontally set simple rotary kiln (Thyssen type);
(b) The inclined simple rotary kiln (Fellner and Ziegler type);
(c) The inclined double rotary kiln (KSG—Stinnes type).

Of these three large scale constructional types only the last was able to hold its ground in Germany in the low temperature carbonization of bituminous coal. It may be permitted, in connection with this, to point out the bases for the success of this last named retort and to refer to certain considerations which are valid for low temperature carbonization in general.

The first named type of construction is set horizontal as may be seen in Fig I. The passage of the coal through the retort is due to the helix fastened to the inner surface of the cylinder and to the rotation of the cylinder itself. To carbonize the coal a temperature of 500-600° C. is necessary. But at this temperature the strength of a cylinder about 20 meters long which is supported only at its two ends is only very small so that the cylinder under the influence of its own weight and of the weight of the charge may sag unless extremely great wall thicknesses are used.

A coal as mined contains generally up to 3% moisture. The removal of this moisture uses up a certain proportion of the available heating surface and to this extent a certain section does not participate in the special function of the retort, namely, carbonization. As soon as the coal, provided it cokes well, has reached its softening temperature it passes to some extent over into the plastic state, that is to

say, small lumps are formed which stick more or less to the retort walls and clog them up or encrust them as the carbonization proceeds or they coke together to form large lumps. The encrustation forms a heat insulating layer on the inner surface of the inner drum (carbon is a very poor conductor of heat); that is to say, that independently of any other operating difficulties produced thereby, a strongly coking coal after a short time prevents any further penetration of heat as even the coal which has already become heated can no longer be distilled because of the insulating crust and, as tests have shown, the formation of massive lumps increases until the retort is plugged up. Tar and gas are drawn off in the horizontal type of retort in the same direction as that in which the semi-coke moves. The production of dust is unavoidable due to the rotary motion of the cylinder. Dust and tar collect together on the same area of the cylinder. The dust which is contained in the tar is thus semi-coke dust. But semi-coke dust is wetted very poorly by tar. Furthermore it has a low apparent specific gravity (0.7), floats on the tar and produces a very tenacious suspension which separates out only imperfectly and with great difficulty on allowing the tar to settle. Such suspensions, moreover, increase the emulsifying power of an oil so that the separation of water carried over with the tar does not occur or is far too slow without the use of mechanical aids.

To evaporate the moisture content of about 3%, about 20% of the total heat applied must be used. Thus, as was mentioned before, a large part of the heating surface is used only for drying purposes, that is to say, the first part of the retort is not a carbonizing retort at all but primarily a drying kiln.

The inclined type of construction exhibits the same phenomena as pointed out above. The coal moves along the inner surface of the retort due to the rotation and the weight of the coal. Here, too, there is danger that the cylinder just as in the first case will sag unless sufficiently heavy walls are provided. Semi-coke and gas emerge from the kiln in the same direction. As tests have shown the same difficulties arise as in the case of the horizontal type, namely, incrustation and clogging of the cylinder when strongly coking coals are put through and also a high dust content in the tar. In both types of retort there can be used only coals which are not highly coking. Both constructions are thus limited to specific varieties of coal or bituminous fuels. But a good low temperature carbonization retort may reasonably be expected

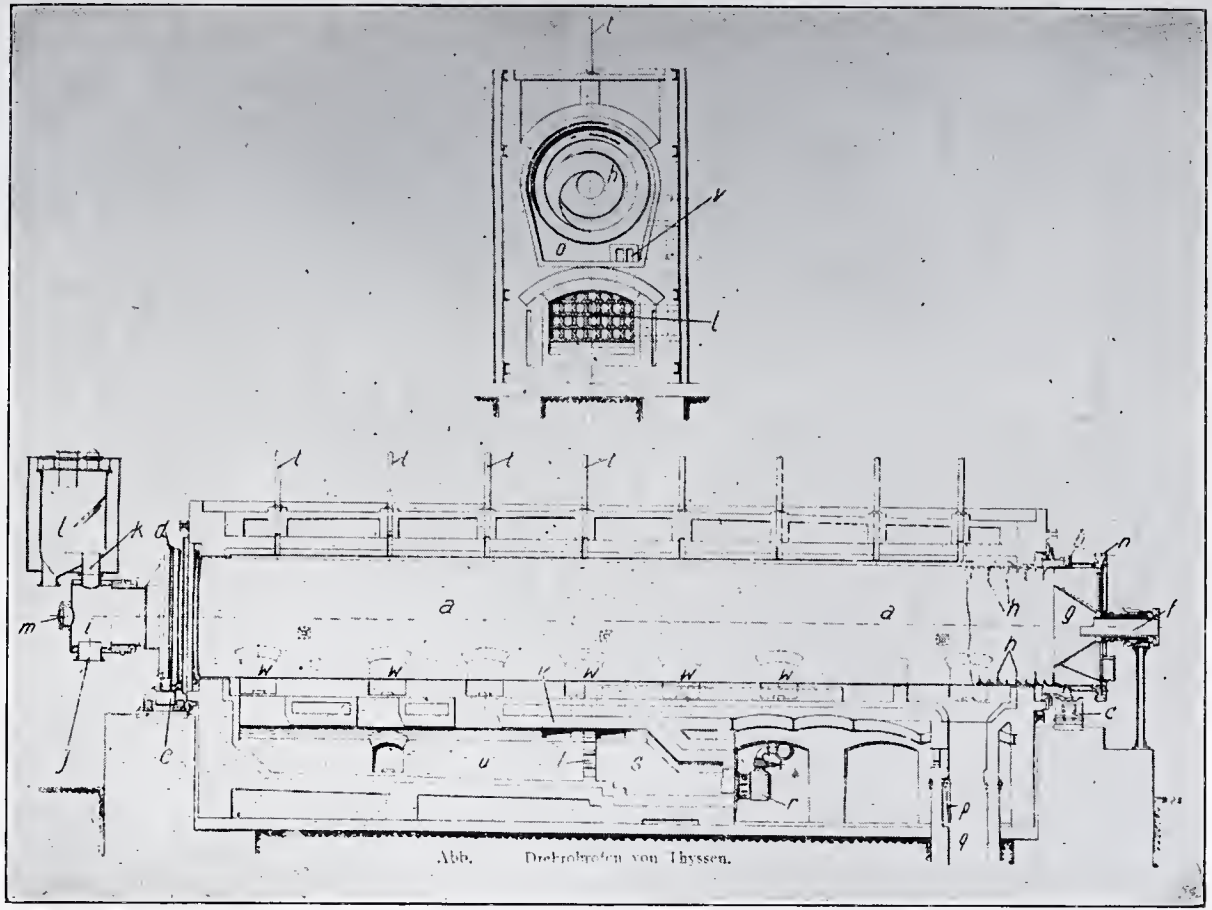

FIG. 1. THYSSEN ROTARY RETORT

to be able to handle any coal having a fair coking power and not only coals of a definite particle size but also low grade pulverized coals, for this refining of form from a dust to a solid fuel in lumps normally determines the industrial value of the process.

This requirement is fulfilled by the inclined double rotary retort. Such a retort has been in successful continuous operation at the carbonization plant of Mathias Stinnes at Essen-Karnap. The constructors of this retort are the "Kohlenscheidungs Gesellschaft m.b.H.," Berlin. The fundamental difference from the previously named types consists in the fact that we have two cylinders arranged concentrically, one within the other. Fig. 2. The coal to be carbonized is fed in at the lowest cylinder head and is moved upward in the inner cylinder by a helix. The inner cylinder which supports the outer cylinder never reaches a temperature above 300° C. and is thus in a temperature range in which cast iron has its maximum strength. As a result the system possesses increased rigidity. It is naturally understood that the wall strengths of the inner and outer cylinders are so designed that the above mentioned effect is made full use of. As the inner cylinder in agreement with repeated measurementst has a temperature hardly ever above 300° C. (radiant heat from the external cylinder) the coal is dried there and prewarmed exclusively. At the upper end it falls into the outer cylinder along which it passes because of the rotary motion and its own weight. In the outer zone the coal is heated up very rapidly and it arrives in the shortest possible time at the carbonizing zone indicated in the sketch. It has been found in the course of tests that this intentionally produced rapid carbonizing of the coal is an important feature. In the rapid carbonization zone through which the coal passes relatively quickly, the coal becomes plastic, but as a result of the short time it remains there it cannot become coked into large masses as was in the case in the constructions previously mentioned but instead it agglomerates only to a certain extent. The size of the lumps of semi-coke can be determined by the size and position of the carbonization zone.

The addition of a small amount of highly superheated steam (450-550° C.) to the retort helps considerably in producing and maintaining the uniformity of the semi-coke. The steam fulfills several purposes. In the first place it distributes the sensible heat uniformly over the charge. Furthermore it breaks up the coal mechanically to a certain degree while it remains in the plastic state and assists in preventing a

sticking together or coking of the charge (to the extent that coal which can coke is present). Furthermore it helps to lower the optimum carbonizing temperature, that is, the temperature above which the yields do not appreciably change qualitatively and quantitatively. This can easily be understood if we remember that the coal at the point of softening possesses a definite vapor pressure which consists of the sum of the partial pressures of the individual components. By the addition of a new gas phase (steam) the individual partial pressures are lowered under the conditions of constant total pressure. According to the well known laws of physical chemistry which operate in such a case this lowering of the vapor pressures results in a lowering of the boiling point which in turn causes a decrease in the so-called optimum carbonization temperature under consideration. It has been determined numerically that in the case of the Mathias Stinnes coal the use of 5-10% of steam (on the weight of coal) lowers the coking temperature about 20° C. below that obtained without steam. Finally the steam is able to influence the coal in a purely chemical manner because experience has shown that the addition can be carried out in a manner to overcome the undesirable puffing property of a coal without decreasing the coking property necessary for the process. It may also be mentioned in passing that the addition of steam influences the production of crude tar favorably from a purely physical point of view.

By all these conditions: regulation of steam addition, position and temperature of the carbonization zone, speed of the rotation, it becomes possible to produce a semi-coke of greater or lesser strength, that is to say, we can to a degree determine and control from the laboratory analysis of a coal how it must be carbonized to yield a semi-coke of specified properties.

The semi-coke produced in the KSG double retort is a homogeneous fuel in every respect. Due to the fact that the rotary retort turns over the coal carbonized in it continuously and always uniformly due to the built in rotary drive, the physical and chemical properties of the semi-coke must be such that there is no distinct difference between the center and outside of each lump. Such a homogeneity is not attainable in any of those processes in which the charge receives its heat treatment while at rest (in the chamber or cell retorts) or in those in which the coal is not being continuously turned.

The semi-coke is discharged from the lower end of the retort, that is, it is removed at the point where the charge is fed in. The distillation

products are drawn off countercurrent and thus are not subjected to a secondary cracking process. The drawing off countercurrent has the advantage that no semi-coke dust is drawn off in the gases; at the most some coal dust is withdrawn with it but this can easily be separated for the reasons given above. That the dust problem is thus solved in a practical manner appears from the following data. The crude tar produced in the KSG retort contains 2-5% of water and 2-5% "free carbon" (insoluble in benzol). That the dust present in the original tar is coal dust which settles out easily as has been stated, and not semi-coke dust has been determined by analysis.

The consumption of fuel for the underfiring remains very small due to the use of the so-called rotary flame. The gas necessary for the heating is burned with the minimum excess of air leading to the highest degree of thermal efficiency. The necessary lowering of temperature is produced by adding a certain amount of the burnt exit gases (300-400° C.) to the burning gases. Thus a part of the flue gases are kept in constant circulation by means of a fan so that the heat content of these exit gases is being constantly improved in the combustion chamber. The fresh air drawn in for combustion and also the flue gases discharged through the chimney are thus kept down to a minimum.

In the KSG—Stinnes kiln, as is shown in Fig. 3, the temperature rises in the inner cylinder as measurements have shown relativelly rapidly to 100° C. and then rises slowly. In the inner cylinder the drying and preheating of the coal occur. The temperature then rises rapidly in the outer cylinder until the carbonization temperature is reached. The area shown cross-hatched represents the carbonization zone. Due to the fact that the carbonizing temperature is maintained for a considerable period, a completely distilled coke is produced.

A further important point in the low temperature carbonization is the cooling of the semi-coke taken out so as to yield a high grade lump semi-coke. The use of water quenching did not result in a penetration of the entire lump of coke by water. Thanks to its extremely large inner surface semi-coke has a very high reactivity similar to that of charcoal. As a result of a certain secondary gasification in the case of large lumps and a result of the high reactivity mentioned semi-coke is very liable to spontaneous ignition. The most varied proposals and methods of operation have not yet made it possible to prepare a product with 1 to 2% of moisture such as is obtained in the water quenching of blast furnace coke. Therefore new methods have been sought in low temper-

ature carbonization, and dry coke cooling was applied to semi-coal although there is no recovery of heat values due to the small temperature drop. Use is made of dry cooling of semi-coke only to improve the quality of the coke produced. Several advantages are obtained thereby. In the first place dry cooled semi-coke is distinctly harder than the wet quenched product. It is easy to see that the relatively spongy structure of semi-coke causes water quenching to produce a certain amount of cracking or at least to render the surface friable. A further advantage of dry cooled semi-coke is its practically complete freedom from

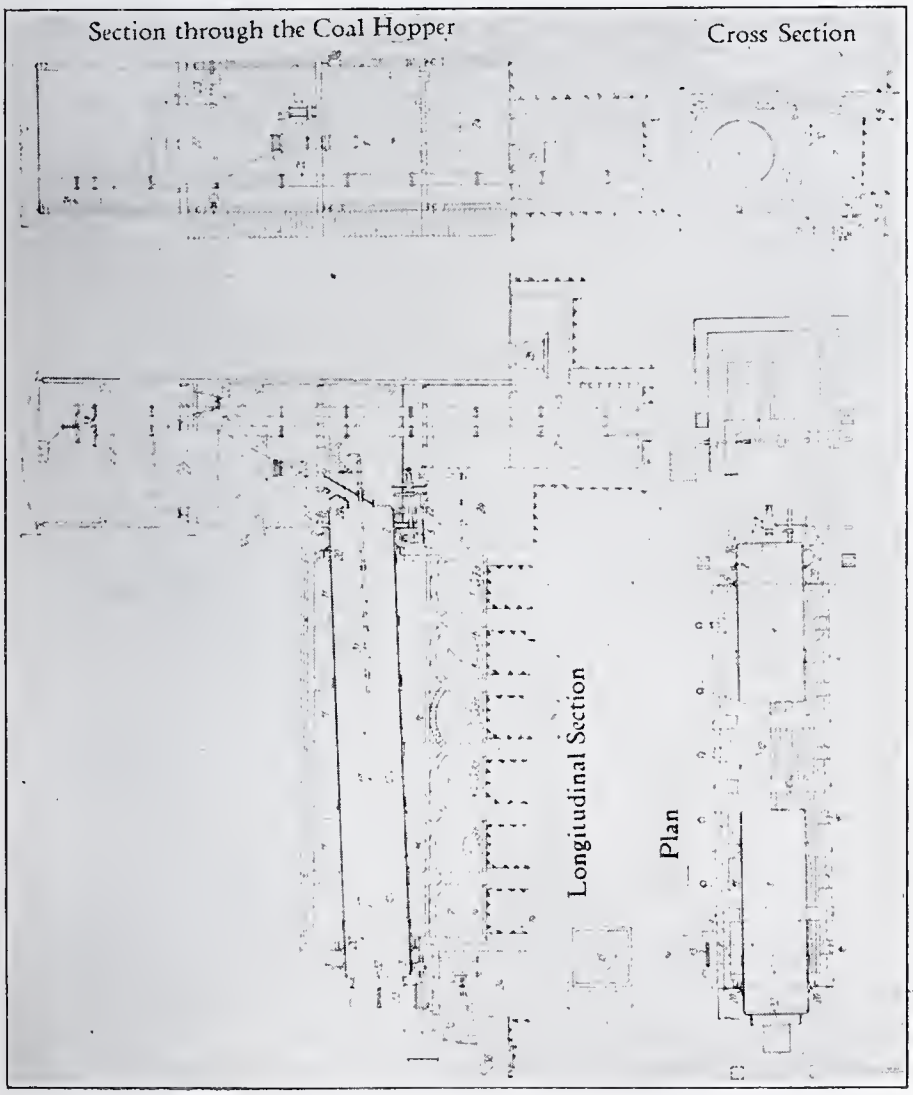

Fig. 2. Retort for Low Temperature Distillation at the Gelsenkirchener Blast Furnace Plant

moisture. Finally and most importantly the increased proportion of large size coke is to be noted. Whereas in the case of wet quenching the ratio of fines (0-10 mm. size) to large (10-90 mm. size) on the average amounted to 45:55, this ratio altered at once on the introduction of dry coke cooling in favor of the larger sizes so that it became 25-30:75-70. It is unnecessary to dwell on the importance of this fact. It need only be stated that this increased proportion of larger sizes in all cases influences the value of the process quite favorably.

The details of a dry coke cooling installation are as follows: the semi-coke emerging from the double retort is first broken up and screened hot in the absence of air. The finer sizes, 0-10 mm. go to a bunker which is traversed by simple air lines. The cooling of this part is thus carried out by means of indirect air after it was found that the fines on close packing would choke off the air supply to a certain extent.

The large sizes pass from the air-tight storage chamber into the true cooling chamber. The coke conveyor is guarded against false air by a special water seal. On putting the system into operation for the first time the fan forces the air present in the system through the hot coke;

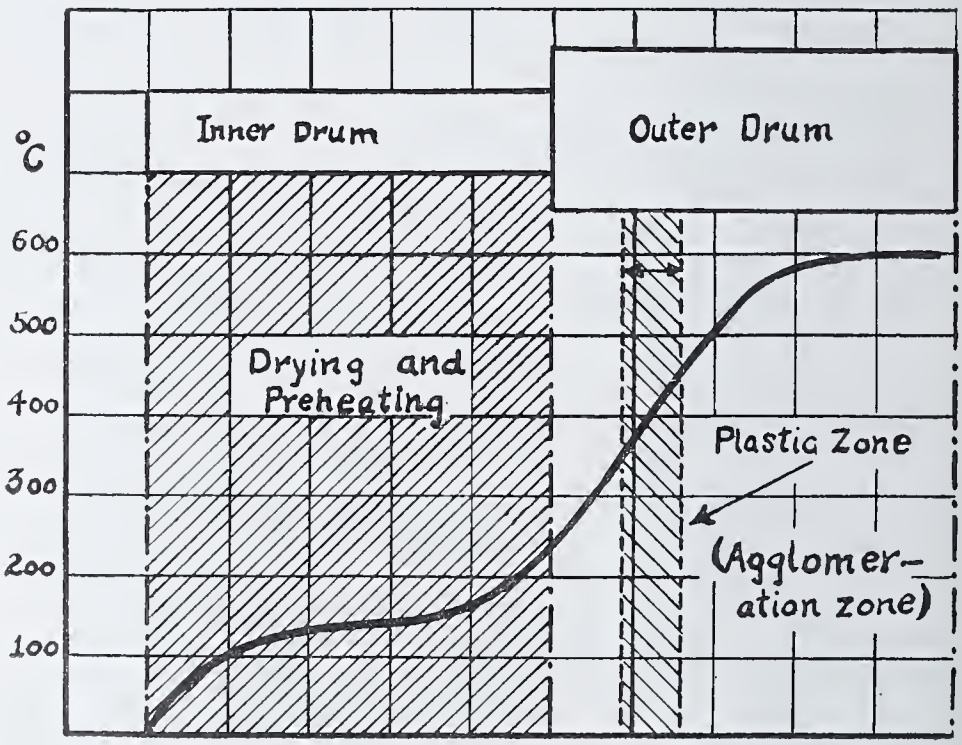

Fig. 3. Temperature Distribution in the K. S. G. Drum

the oxygen is consumed by combustion and a CO_2-CO ratio is obtained corresponding to the equilibrium conditions for the temperature prevailing. The hot combustion gases pass from the cooling chamber into a cooler where they are cooled by direct spraying of water to the desired temperature. The water spraying results in a simultaneous washing out of the carbon dioxide. After establishing equilibrium conditions in the cooling gas circuit the following composition was found:

1.4 volume % CO_2
0.6 volume % O_2
1.0 volume % CO
0.4 volume % H_2 CH_4
96.6 volume % N_2

As is seen we have a completely inert gas due to the nature of the construction of the cooling system.

A semi-coke cooled in this manner showed the interesting property that its surface is to a certain extent waterproof. Large piles of semi-coke which lay in the open for about 1½ years and were thus exposed to the changes in weather of both winter and summer show today an average water content of not more than 2% and a maximum of 5%, that is, the centers of the individual lumps are still practically anhydrous. This fact is easily explained if we consider that the semi-coke is to a certain degree a coke not completely de-gassed and is still fuming a little when it leaves the retort. The traces of tar vapors are obviously condensed at once on the surface and impregnate the lumps of coke somewhat when the coke enters the cooling chamber. The fact is that in every case dry cooled semi-coke which has lain for days in heavy rain always shows a perfectly dry interior. That this resistance to the weather of dry cooled semi-coke is exceedingly advantageous in every respect needs no particular discussion.

In conclusion we might point out the various fields of use of semi-coke, both of the fine sizes and of the large sizes.

The small coke can be used without any further treatment as material for coal dust combustion installations as has been shown by extensive tests. At a fineness of 80% (4900 mesh screen, i. e., 70 meshes to the linear centimeter or 175 to the inch) it ignites easily even in a cold fire box and burns with an excellent flame like any other good pulverized fuel. Particularly striking but easily explainable by the

easy igniting power of semi-coke is the minimal content of combustible material in the ash.

Briquetting of the fines is obviously possible without any further treatment if there is any need for this type of fuel, that is, if the price obtainable for briquets makes briquetting economically feasible.

That semi-coke fines can be used successfully instead of low volatile coal fines for certain metallurgical purposes such as, for instance, working up zinc, may be mentioned in passing.

One of the most important applications of the semi-coke fines is the doctoring with it of coking coal to improve the quality of metallurgical coke. It may be mentioned that the hardness of coke increased appreciably after adding semi-coke fines to the coking coal and the abrasion (determined by the Breslau tumbler method) decreased by 12% if the total abrasion of the mixed coke is called 100%.

In comparison to the possibilities for using the large sizes the fines play a secondary part both from the point of view of quantities available and also from a consideration of the importance of the uses described above.

The large semi-coke is a splendid generator fuel as has been determined by test. In addition to high efficiencies large outputs can be obtained. Generator gas produced from semi-coke was found to have the advantageous properties of high grade coal generator gas without the disadvantages of the latter such as tarring and clogging of the lines and boosters. This is particularly advantageous in the use of semi-coke for suction installations. Very satisfactory operating results were obtained as no clinker formation occurred contrary to results obtained with earlier products. The content of combustible in the ash was a minimum. The ash itself was perfectly granular.

For the sake of completeness it might be mentioned that semi-coke lumps have been used successfully in foundries. It must however be emphasized that the most important use of semi-coke is as a domestic fuel. That there is a great outlet for semi-coke is indicated by the fact that the demand for semi-coke in the neighborhood of the coking plant has never yet been filled.

From this last fact that it is marketable, i. e., that a hard and sufficiently dense semi-coke in lump form can enter the market for solid fuels at once, it follows immediately that at least in Germany there is a need for the low temperature carbonization of bituminous coal. In

this situation the specific problem of low temperature carbonization is not to glut the market with unmerchantable fines.

In general the low temperature carbonization of coal will be economical wherever a coal is available which can be carbonized without further treatment and which can be refined as a result of its high volatile content to yield a maximum output of oil and simultaneously of a residue in the form of large lumps.

The economy of the KSG—Stinnes process which has been described in detail is always assured wherever there is available a bituminous coal suitable for low temperature carbonization, i. e., a high volatile more or less coking coal in the form of small sizes. No standard can, however, be set up. In each case the geographical and manufacturing conditions for the suitability of low temperature carbonization must be individually considered.

The foregoing lines have shown that the inclined double rotary retort offers a means to the mining industry or the allied circles of carrying out a low temperature carbonization successful in every respect.

THE BUSSEY PROCESS OF LOW TEMPERATURE DISTILLATION

By Richard B. Parker
Consulting Engineer, New York

About thirty years ago I did my first work on the distillation of coal at the first, and at that time, the only by-product coke plant in the United States.

I have, as the boys then used to describe their jobs, been "shoveling smoke" ever since, and at no time during that period has the outlook for a real advance in the art of getting a truly smokeless fuel to the consumer at a reasonable price been so good as it is at present.

The following paper has been prepared on rather short notice and no attempt has been made to make it technical. I have merely attempted to describe the apparatus used in the process and to tell you what its products are, and how they are produced. I have omitted all description of the by-product recovery apparatus because in common with most other similar processes, standard cooling, condensing, and scrubbing apparatus is all that is required.

As a foreword, I wish to say that in attempting the development of this process, we have endeavored to attack the problem from the practical rather than the theoretical side; and our chief object has been, and is, to produce a cheap smokeless fuel, with the least expenditure of labor, and the greatest possible recovery of the original heat value in the coal.

Producing a fuel that Mr. John Smith, consumer, can buy to replace his present source of heat without seriously diminishing the balance from his weekly pay check, to use a comparison—we are not attempting to produce a Packard car, but just a flivver that anyone can afford to buy and use.

The process of Low Temperature Coal Distillation covered by the Bussey Patents is perhaps the simplest in conception of the many similar processes now under experimentation or attempted development.

It consists literally of maintaining combustion of a mixture of air and gas in the lower end of a vertical column of coal, which is confined within an air-tight, brick-lined stack, and in removing the consequent products of combustion together with the evolved gases from the top of the

stack by drawing or forcing them through the superimposed mass of coal. The devolatilized carbon residue is removed from the base of the stack as formed, and fresh raw material in equal volume added to the top of the column, as the charge settles, due to the action of gravity.

The design of the retort is comparatively simple, and compared to the retorts used by many other processes, relatively inexpensive.

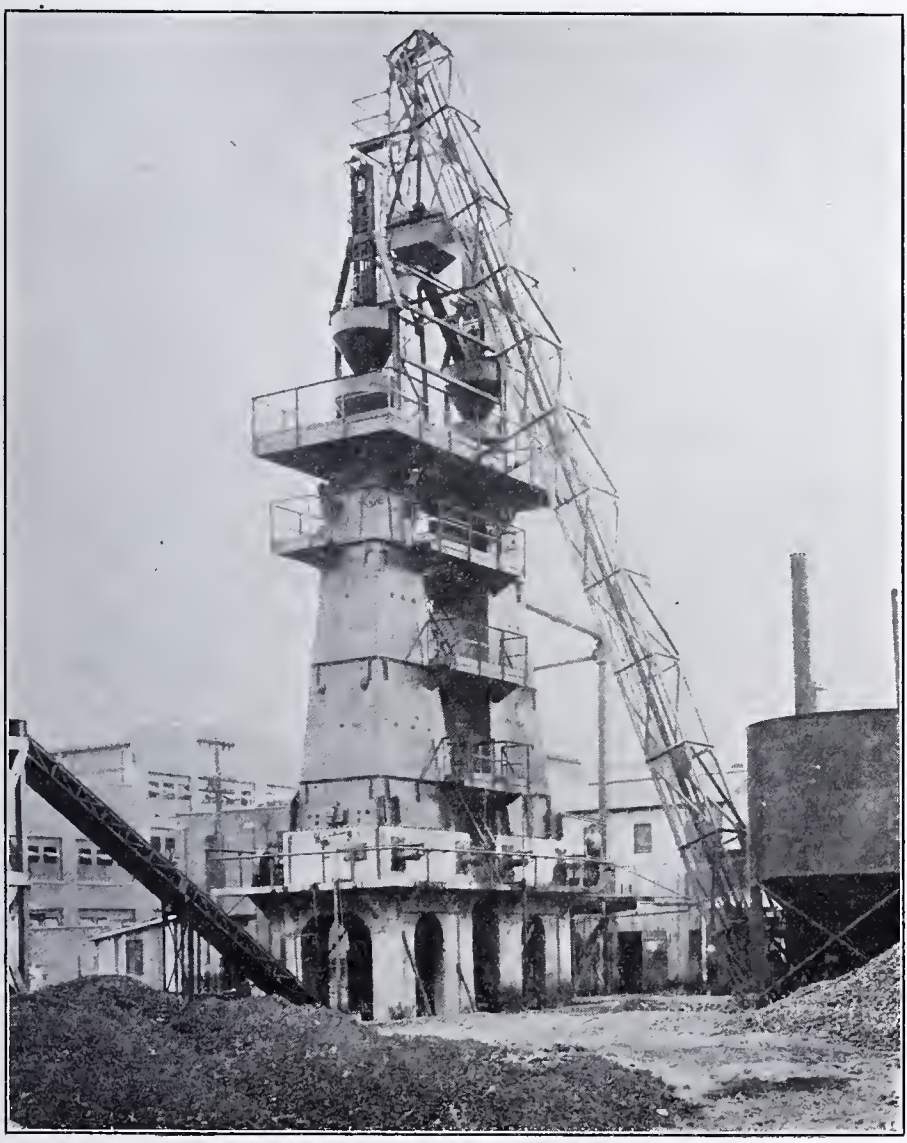

FIG. 1. THE BUSSEY PROCESS

When the process was first brought to our attention several years ago, with a request for advice as to further development, our first reaction was that the process was so absurdly simple that if it had any real merit it would have been worked out years earlier; and our advice to our clients was to stop throwing good money after bad, and to scrap the experimental plant at Louisville for what it would bring.

In spite of this advice, our clients were determined to make another attempt to operate the plant, and we were employed to correct the more obvious faults in design and construction, and to supervise its operation. We were frankly skeptical that any result would be obtained other than failure, and were much surprised to find that the retorts performed very nearly in accordance with the claims of the inventor.

A somewhat intermittent operation was carried on for a period of eighteen months, during which we processed 28 different coals, ranging from high ash mine refuse and dirty Illinois slack, through the whole series of high grade bituminous coals to cannel coal.

We were able to produce oil, gas and salable carbon residue from all of these coals, and were able to make the retort function with fair regularity.

In all, we processed during this period about 2500 tons of coal from which we recovered and sold about 1500 tons of carbon residue.

The rate of operation varied from 12 tons per day to 25 tons per day, and depended very largely on the physical condition of the coals charged and their other inherent qualities. The slower operation was on fine slacks and coals having a low melting point. The more rapid operation on the sized coals of less coke-ability, and the most rapid operation on the splints and cannel coals.

The results obtained from the single retort then in use were sufficiently encouraging to indicate that the process had more than a fair chance of ultimate commercial success, and it was decided as the next step in development, to build two new retorts in which more obvious faults in the original installation were corrected, and which would allow operation on a sufficiently large scale to demonstrate the true commercial possibilities of the process.

These new retorts were completed last summer, and have been operated for several months with what are really very encouraging results. They are comparatively simple in construction, being steel stacks supported on a concrete base, and lined with fire-brick. Their general form is that of a truncated, rectangular pyramid. The coking or dis-

tillation chambers being 2 ft. sq. at the top, with a height of 30 ft.; and a rectangular base 8 ft. by 3 ft.

As the process demands the maintenance of a vacuum at the top, and a pressure at the base of the apparatus, they are equipped with specially designed double feed-hoppers, fitted with interlocking valves operated by hydraulic cylinders on top, and a similar arrangement of double discharge-hoppers below the retorts.

In normal operation the retort chamber is kept completely filled with coal at all times, the charge being supported on a rectangular floor or grate below the base. This grate is hollow and divided into sections through which the air, gas, and steam, necessary for the operation are admitted, and is adjustable as to its vertical position in relation to the base of the retort.

Above the grate is the discharge mechanism, which consists of a hollow water cooled cast steel cutter-bar having a slow reciprocating movement at right angles to the grate's longest dimension. This is actuated by a screw mechanism driven by a small motor. The action of this bar pushes the portion of the charge immediately above the grate off of the opposite side of the grate from which it enters, and after traveling completely across, reverses and pushes the next cut off the opposite side of the grate. Its speed may be varied to suit the desired rate of operation.

The carbon residue discharged, falls into the first of the air-tight hoppers below, where it is quenched with exhaust steam supplemented when necessary by a water spray.

These two new retorts have been operated for several months, and give every indication that successful commercial operation is a practical possibility. During this period five additional coals have been successfully processed, and the retorts show no sign of failure in any respect. Repairs have been practically negligible.

The operation of the retort is simple and requires very little manual labor. Combustion is maintained within the charge at its base by forcing the required amounts of air, gas and steam through the previously mentioned floor or grate, which is so arranged that the amounts admitted to any given section of the grate may be varied at will from without the retort.

The products of combustion together with the gases evolved are removed from the top of the retorts by a steam engine driven exhauster.

The coal is unloaded and placed in a self emptying steel bin, from which it is delivered to an automatic, electrically driven, self loading

skip-hoist, which discharges it into a small hopper above the retorts. Electric connections governed by the depth of coal in this hopper automatically control the movement of the hoist in such a manner that this hopper is maintained full at all times. The coal is fed by gravity from this small hopper to the two upper feed hoppers on the retorts which are also maintained full at all times.

The cycle of operation is as follows: The mechanism operating the cutter-bar that discharges the retort is set in motion and as it completes its first movement across the grate it operates the mechanism controlling the operation of the discharge valve on the upper feed-hopper to which it is connected, and causes this valve to open and allows the coal to fill the lower feed-hopper. This valve then automatically closes and locks shut. The cutter-bar then reverses its direction of travel and as it completes its return stroke it causes the valve on the lower feed-hopper to open and allows the coal to fill the retort, after which this valve also automatically closes and locks shut. Provision has been made for separate manual operation of these feed-valves if desired, but the mechanism is so arranged that only one valve can be opened at a time, and both valves automatically close if not held open. This is a necessary precaution because of the vacuum normally maintained on the top of the retort.

The carbon residue discharged from the base falls into the first of the discharge hoppers where it is quenched as received, and when a sufficient quantity has accumulated it is dropped to the lower discharge hopper and from that to the conveyor which carries the coke to the screening plant.

The control of the operation is not difficult. The operators' chief duties being that of watching the temperatures and pressures as indicated and recorded by the thermometers, pyrometers and gauges placed at critical points on the retort, and noting through observation ports the condition and temperature of the combustion zone near the base.

Control is maintained by varying the suction at the top, the pressure at the base, and by the amount of air, gas and steam admitted through the grate, and by varying the rate of operation of the discharge mechanism. By the proper manipulation of these factors a graduated temperature from the bottom to the top of the retort can be maintained as desired.

While the design and operation of the retorts present no unusually difficult problems, the reactions within the column of coal are extremely complex and as yet little understood.

Our investigations to date indicate that the distillation may be considered as divided into three separate stages which take place in three separate zones which merge into each other. The first stage being that in which the incoming coal is heated by the passage through it of the evolved gases from below to about 300° F. The mass of coal becomes considerably saturated with condensed oils in this zone, and these oils are constantly returned with the advancing coal toward the source of heat to be revaporized and again advanced toward the gas outlet.

The heavier portions undoubtedly fall with coal into the second stage or distillation zone, which may be considered as that portion of the retort in which the temperature range is between 300° F. and 800° F. In this zone the charge is in a somewhat pasty mass thoroughly saturated with the condensed oils returned from above, the lighter portions of which are vaporized and join the gases evolved from the coal in their upward sweep through the superimposed portion of the charge. A considerable amount of the heavier portions or pitches from these oils undoubtedly join and fuse into the mass of carbon residue, and eventually pass through the combustion zone and finally out of the retort as pitch coke incorporated with the mass.

The third stage is that of hardening or setting the carbon residue and lowering its volatile content to the desired point. This takes place in the last or combustion zone, in which the gas and air are burned to supply the necessary heat to carry on the process. Considerable carbon-monoxide and hydrogen are also produced in this zone by the action of the steam introduced through the incandescent carbon mass.

It is obvious that the Bussey apparatus is not only an apparatus for distilling coal but also has some of the characteristics of a tar still, a gas scrubber, and a gas producer; and determination of just what reactions take place at any given point within the retort is a quite difficult problem.

Operations to date have indicated that the retorts are remarkably efficient as heat interchangers, and that the thermal efficiency of the process is extremely high. All attempts yet made to establish the heat balance of the process have indicated such a high percentage of efficiency that we are unwilling to quote the figures until we have accumulated further data

by continued operation. The efficiency however must be very high because of the fact that the evolved gases and products of combustion are all cooled by the incoming coal to a temperature only slightly above the boiling point of water, and because even the heat evolved from quenching the final product is returned to the retort. The radiation losses are negligible.

The quantity and quality of the oil, gas, and carbon residue recovered from the different coals charged varied greatly. Changes in methods or manner of operation were also notably instrumental in causing variations in the products made.

From the results obtained while operating the retorts on 34 different coals we have processed to date, we can say that the average yield of carbon residue has equaled the percentage of fixed carbon plus the ash in the coal charged. That the yield of tar oils has varied from a minimum of 15 gallon to a maximum of 35 gallon per ton of bituminous coal charged, and that a yield of approximately 25 gallons may be expected for any fair grade of high volatile bituminous coal. The cannel coal gave oil yields from 50 gallons to 110 gallons per ton of coal charged, but the oils were markedly different from those obtained from the bituminous coals. The ammonia yield from all coals was so small that its attempted recovery would be unprofitable. The gas yield varied from 20,000 cu. ft. to 30,000 cu. ft. per ton of coal charged, the volume varying slightly with different coals but being subject to a very large variation when changes in methods of retort operation or control were made. The B. t. u. content of the gas averaged about 250 when the retorts were functioning normally.

Experimental work carried on with a view of determining how the heating value of the gas made can be improved, indicates that a yield of 20,000 cu. ft. of 300 B. t. u. gas can probably be successfully obtained, and that a gas of samewhat higher B. t. u. value can be produced, but that the volume produced will fall off materially as will the thermal efficiency of the apparatus when operated with this end in view.

The carbon residue recovered from all coals yet processed has had all the characteristics of a good domestic fuel, its size being that of a mixture of egg and nut coke. Tests indicate a remarkably greater combustibility than that of high temperature by-product coke, and when we have processed coals used elsewhere in high temperature plants previously

under our direction or management, we have found that the density of the Bussey Coke was from 15% to20% greater than that obtained from the ordinary by-product oven.

These two improvements in quality open up the rather interesting possibilities which of course are not yet proven, that the Bussey Coke may be found to have distinct advantages as a fuel for water gas manufacture and metallurgical coke.

I have inserted here a few characteristic analyses of the gas, oil and carbon residue made that I will not bore you by reading, but will be glad to show later, should any of you desire to look them over.

CHARACTERISTIC ANALYSES

Carbon Residue Analysis

Eastern Kentucky Coal

Moisture	3.24%
Volatile	3.06 "
Fix Carbon	84.06 "
Ash	9.64 "
Sulphur	.46 "

Carbon Residue Analysis

Cannel Coal

Moisture	1.53 %
Volatile	3.45 "
Fix Carbon	88.08 "
Ash	6.98 "
Sulphur	.74 "

Distillation Analysis

Oil produced from Cannel Coal

Sp. gravity	.865
Under 200	13.40 %
200 — 210	12.30 "
210 — 235	21.85 "
235 — 270	19.75 "
270 — 315	12.30 "
315 — 356	8.90 "
Residue above 355	11.50 "
Sp. gravity—fractions 0—235	.82
" " " 235—315	.86
" " 6th, "	.92
Free Carbon	.27 %
Tar Acids 1st —5 fractions	16.5 "
Coke Test	.49 "

Residue above 355 soft vaseline like paste, not a pitch.

DISTILLATION ANALYSIS

Oil Produced from Eastern Kentucky Bituminous Coal

Sp. gravity	1.044
Under 200	.74 %
200 — 210	.65 "
210 — 235	9.10 "
235 — 270	10.60 "
270 — 315	12.70 "
315 — 355	13.05 "
Residue above 355	54.30 "
Sp. gravity 1st — 5 fractions	.98
" " 6th "	1.016
Free Carbon	1.45 %
Tar Acids 1st — 5 fractions	44.29 "

Residue a soft pitch, not brittle.

GAS ANALYSIS

CO_2	11.9 %
O_2	2.70 "
Illuminants	1.15 "
CO	9.2 "
H_2	21.85 "
CH_4	10.1 "
N	43.1 "
B.t.u.	237.3 "

The operation of the retorts to date indicate that the process has three interesting possibilities, that are not possessed by any other coking process of which we have knowledge.

The first of these, is that with proper handling it is possible to reduce the sulphur content of the carbon residue to a very low point irrespective of the amount of sulphur in the coal charged. In one extreme case a coal carrying nearly 4% of sulphur yielded a coke residue carrying only 1% of sulphur.

The second is that the retorts will produce a fused coke residue from splint and cannel coals which cannot ordinarily be coked.

The third, is that if the breeze made is returned to the retort with the coal charged, it becomes thoroughly amalgamated in the mass of carbon residue without any visible effect on the appearance or quality of the residue.

To sum up, will say, that the quantity and quality of the carbon residue, tar oils, and gas obtained from practically every coal processed to date has been such that we are justified in stating that it is our opinion that full sized commercial plants can now be installed and successfully operated at a profit, at any point where the large volume of gas produced can be marketed at a reasonable price.

Bussey plants can be installed and completely equipped for considerably less than one-half the cost of high temperature by-product coke plants of like tonnage capacity, and many interesting figures can be made showing the adaptability of the process if installed as an adjunct to gas and electric plants making gas which can be enriched to requirements, as blue gas is enriched, making coke which may be used in water gas sets, or utilizing the gas and oil made by converting it into electricity through the medium of Diesel engines or gas engines, or as an adjunct to any industry requiring coke and gaseous fuel, or as an adjunct to coal mines at locations where the gas produced can be marketed at a reasonable price.

THE CRACKING OF LOW TEMPERATURE TARS BY THE DUBBS PROCESS

By Gustav Egloff and Jacque C. Morrell
Universal Oil Products Company, Research Laboratories, Chicago, Illinois

For the next eight hundred years, the bituminous coal deposits of the United States could supply the world needs for motor fuel, at the present rate of consumption. The coal deposits represent the largest known potential source of oil in the world today.

It is estimated that there are 3,154,000,000,000 tons of bituminous coal in the world of which the United States has approximately 1,600,000,000,000 tons. By means of low temperature distillation of this quantity of bituminous coal, 960,000,000,000 barrels of tar can be produced which under cracking conditions will yield approximately 240,000,000,000 barrels of motor fuel of high anti-knock properties. The motor fuel produced from low temperature carbonization and cracking, while operating a high compression motor, will give over double the mileage per gallon of motor fuel when compared to ordinary gasoline using present-day motors. The superior quality of this type of motor fuel is due to the high percentage of aromatic and unsaturated hydrocarbons contained therein.

Low temperature carbonization of bituminous coal has made rapid strides in the past several years. The production of smokeless fuel is a paramount issue in the health of communities. The economic losses due to the smoke nuisance of great cities and industrial centers are tremendous, not alone as to fuel but also the wear and tear of personal effects and the well-being of society. The low temperature carbonization of coal and the cracking of the resultant tar produces a combustible solid having smokeless characteristics and high thermal value. The coke has a calorific value of approximately 16,000 B.t.u. per pound.

During the present International Bituminous Coal Conference we have had the leaders in the field of low temperature carbonization discuss in detail the operation of various processes with their yield of tar, gas, and coke. The present communication deals with the cracking of low temperature tar into commercial yields of motor fuel producing in addition a coke residue practically free from ash and smokeless in quality. In

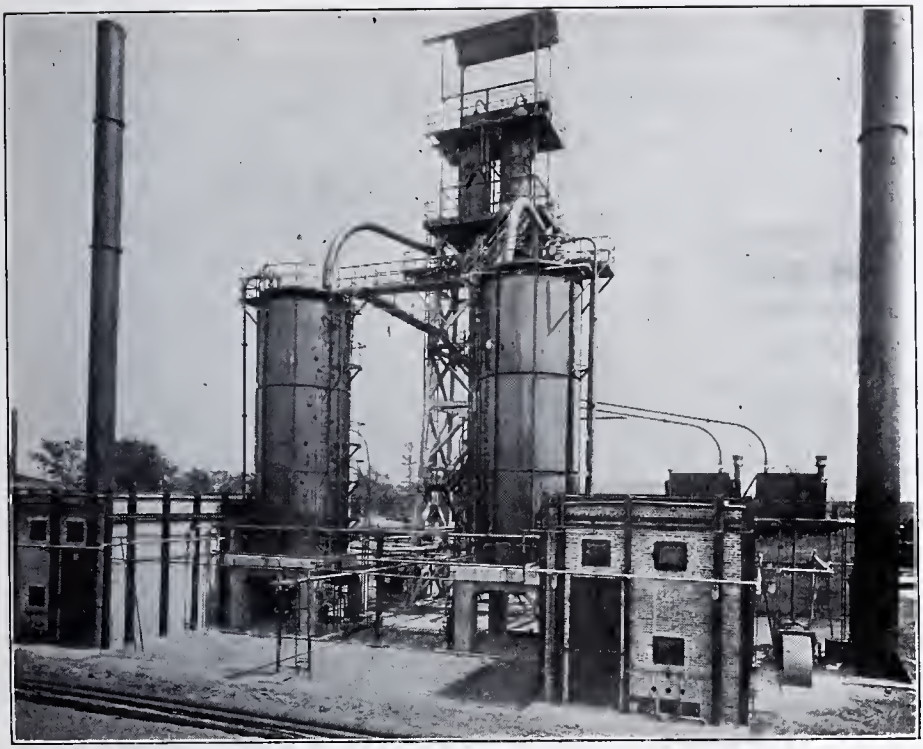

FIG. 1. DUBBS PROCESS

FIG. 2. DUBBS PROCESS

addition a gas of high calorific value is produced which is suitable for enriching water or producer gas.

Results Obtained from the Cracking of Low Temperature Coal Tar Derived from West Virginia Bituminous Coal.

The coal tar, typical of that produced from the low temperature carbonization of West Virginia bituminous coal yielding approximately twenty-five gallons of tar per ton of coal, was cracked under pressure and high temperature. The characteristics of the coal tar used during the cracking operation was as follows:

TABLE I

	Dry Tar	
Coke, %	11.3	
Distillation	Degree F.	Sp. gr.
Initial point	(385)	
10%	475	0.935
20%	513	0.954
30%	554	0.968
40%	584	0.985
50%	649	0.995
60%	673	1.003
70%	694	1.009
80%	740	1.005
90%		
Maximum	(740)	

Water, %	0.3
Gravity of residue	0.957
Flash point1, 07. 2° C. (225°F.)	Cleveland
Fire point, 126.7° C. (260.° F.)	Open Cup
Gravity, specific	1.074
Saybolt Furol Viscosity at 77°F. (25°C) seconds	206

The tar was pressure distilled at 100 pounds at an average temperature of 845° F., producing 30% of motor fuel containing 25% tar acids. On a tar acid free basis a yield of 22.5% of refined motor fuel was obtained.

Summary of Results Obtained from the Cracking of Low Temperature Coal Derived from Ohio-Indiana Bituminous Coal

Another low temperature tar derived from Ohio-Indiana bituminous coal, containing 27.5% tar acids was cracked at 100 pounds pressure and 800° F.

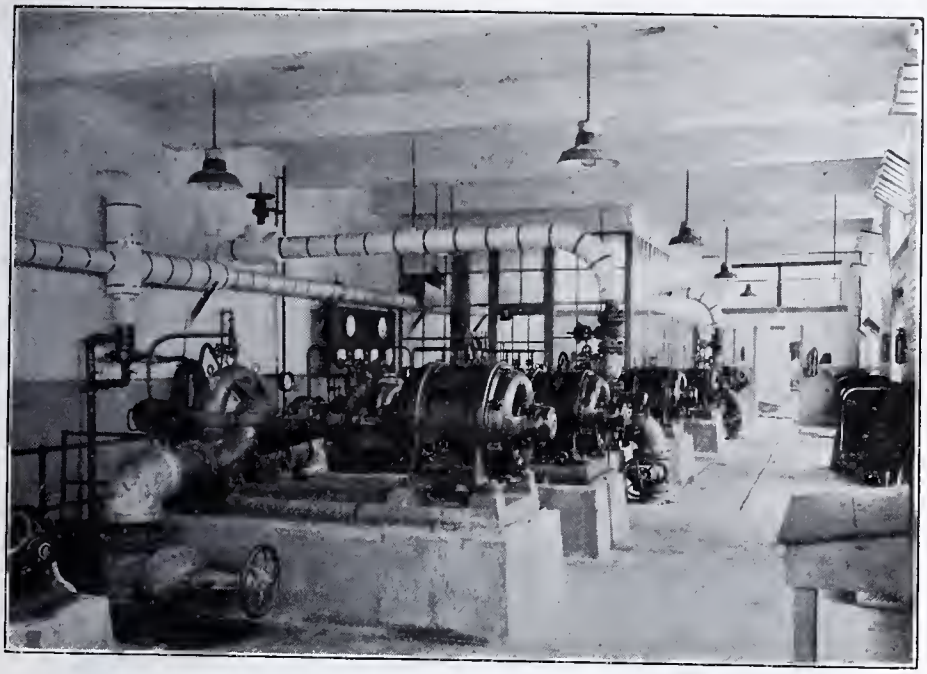

FIG. 3. PUMP HOUSE FOR SIX DUBBS UNITS

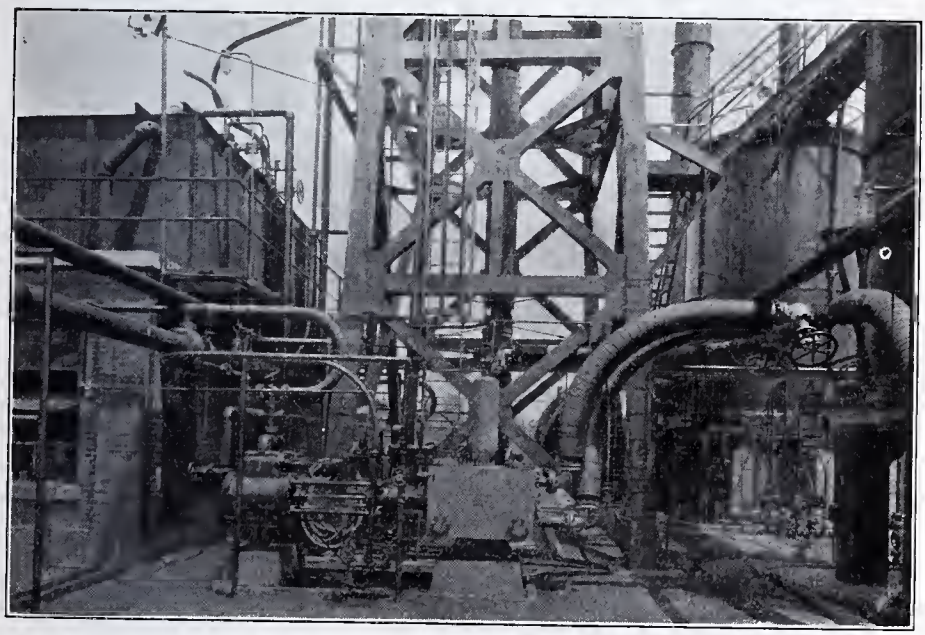

FIG. 4. RECIPROCATING HOT OIL PUMP

The analysis of the coal tar is shown as follows:

TABLE II

Sp. Gr.	1.0794
I. B. P.	240° F.
Flash	130° F. Cleveland Open cup
Fire	180° F. " " "
Furol Visc.	70 sec. 122° F.

Percent Distilled over	Degree F.
10	406
20	450
30	495
40	555
50	658
60	702
78	690

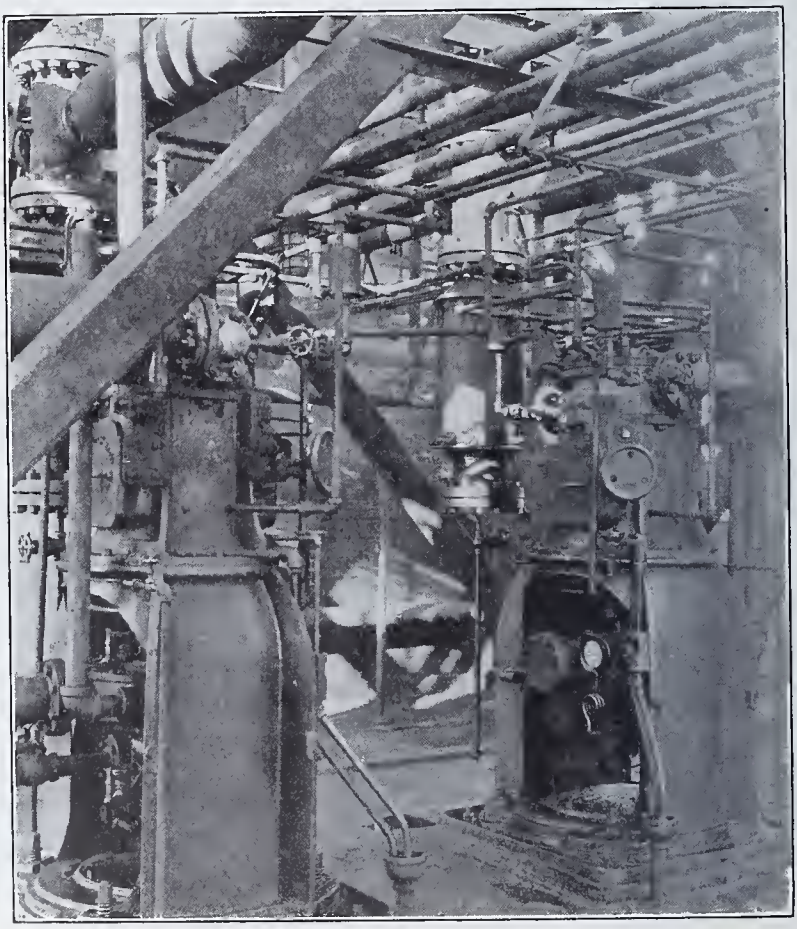

FIG. 5. CENTRIFUGAL HOT OIL PUMP

Coke % by weight	22.
Tar acids %	27.5
Bases %	1.55
Neutral Oils %	28.95

This coal tar under cracking conditions yielded 33.9% motor fuel containing 35% of tar acids. On a tar acid free basis the motor fuel yield calculates 22%. There is no particular reason why tar acids blended with hydrocarbons should not make a good motor fuel.

ESTIMATED ULTIMATE YIELD OF PRODUCTS PER 1000 BARRELS OF TAR CRACKED

Motor Fuel	220 barrels
Tar Acids	120 "
Coke	107 tons
Gas	571,200 cu. ft.

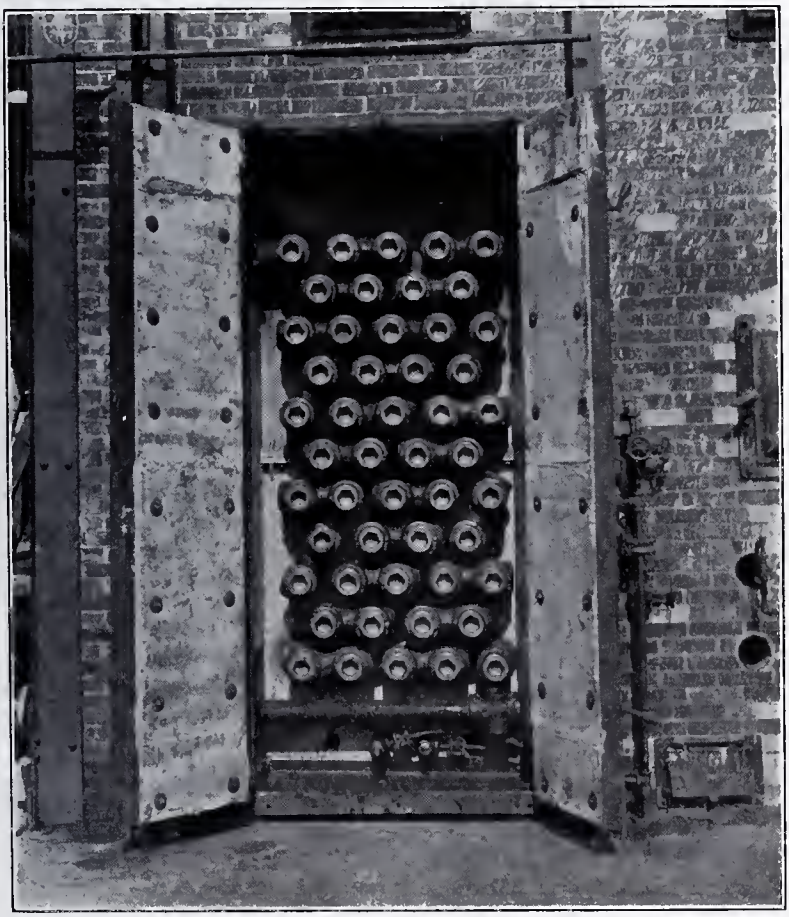

FIG. 6. BANK OF HEATING TUBES, WITH RETURN BENDS AND PLUGS

Treatment of Cracked Distillate

The cracked distillate was first treated with caustic soda solution of about 10% concentration. The tar acids were recovered from the caustic soda solution by neutralization with dilute sulphuric acid.

The residual oil after treatment with caustic soda was treated with dilute sulphuric acid, using approximately ten pounds of 75 to 80% concentration, after which the acid sludge is drawn off and the oil neutralized with a small percentage of caustic soda. The treated oil is then steam distilled to a finished motor fuel.

The tar acids may be added to the motor fuel as desired. Owing to the cyclic structure of the tar acids or phenols, they present enormous possibilities of conversion into varied compounds useful in many arts. It may well be that these tar acids will prove the most valuable of all of the by-products of low temperature carbonization.

Results Obtained from the Cracking of Low Temperature Coal Derived from Ohio-Indiana Bituminous Coal

The following summary shows the results obtained from cracking low temperature coal tar derived from Ohio-Indiana bituminous coal:

Cracking Stock Sp. Gr.	1.0794
Pressure Distillate A. P. I. Gr.	21.8
Per cent of cracking stock	40.8
Coke lbs. per gallon	4.63
Gas, Cu. Ft. per gallon	12.5
Water per cent	3.9
Coke, Gas, Loss	

The motor fuel has a high anti-knock value in operating an automotive engine, representing an aromatic hydrocarbon equivalent of over 50%. The motor fuel as produced contains 35% of tar acids, which may be removed if desired.

Cracking of Neutral Oils

In some low temperature carbonization work it has been found desirable to recover the tar acids and pitch, due to local economic conditions which make this mode of operation desirable.

As a result of this mode of operation a neutral oil distillate is recovered.

This neutral oil is excellent cracking stock. Under pressure distillation conditions of two hundred pounds and average temperature of 850° F. a yield of over 50% motor fuel was produced.

The neutral oil was derived from a West Virginia bituminous coal and analyzed as follows:

TABLE III

A. P. I. Gr.	17.8		17.8
I. B. P.	390° F.		395° F.
E. P.	705° F.	90%	655° F.
Charge, cc's	100		800
Condenser degree F.	Run. Water to dry		Run. Water

Per cent Over	Temperature Degree F.	Temperature Degree F.	Be. Gr.
5	425		
10	450	465	26.6
15	470		
20	480	485	23.3
25	490		
30	505	510	21.6
35	515		
40	530	530	20.1
45	540		
50	555	550	19.2
55	565		
60	575	575	
65	590		
70	610	595	17.1
75	625		
80	640	635	15.7
85	665		
90	695	655	13.8
95	700		
98.5	705		

Remarks

Very Slight Trace of Water	Trace of Water
3 %at 410° F.	1% at 410° F
56 % at 572° F.	57% at 572° F. Be. 21.5
98.5% Over	90% Over
Trace of Coke	10% Bottoms (Solid)

The motor fuel produced from cracking of the neutral oil contained over 50% aromatic hydrocarbon equivalent, thus constituting an excellent anti-knock motor fuel for the operation of a high compression motor.

The coke formed represents two pounds per gallon of the neutral oil cracked. This coke has a calorific value of 16,000 B.t.u. per pound, and is practically ashless.

The gas formation represents 20 cubic feet per gallon of neutral oil cracked. This gas has a calorific value per cubic foot of approximately 1300 B.t.u.

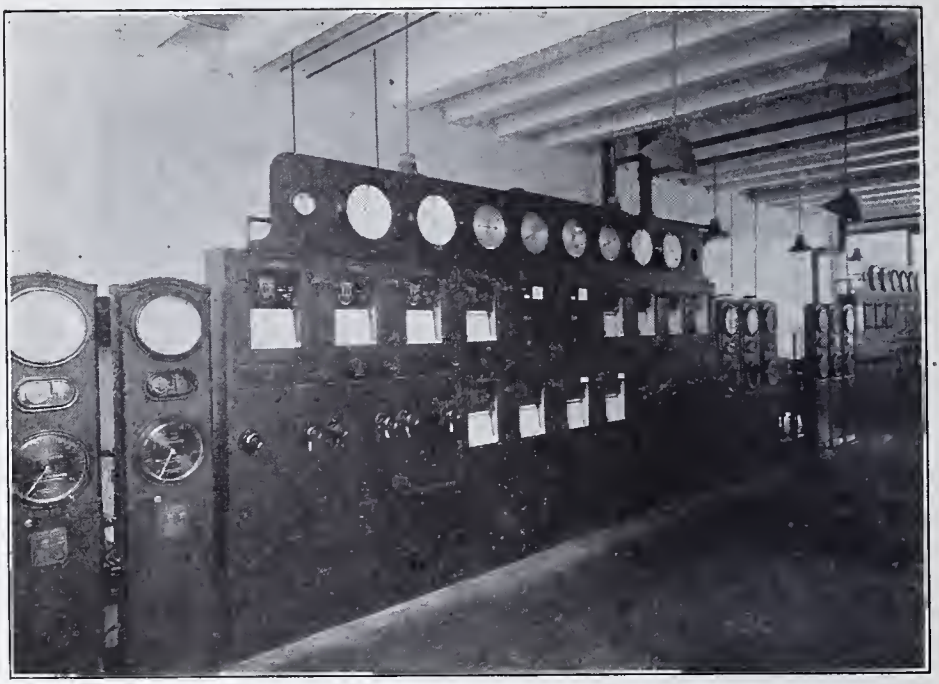

FIG. 7. CONTROL HOUSE

THE OPERATION OF THE DUBBS CRACKING PROCESS.

Owing to the arrangement of its various principles the Dubbs process is most suited for the cracking of high coke forming oils such as low temperature coal tar or its fractions.

The adaptability of the process has been strikingly shown due to the fact that it is cracking the most diversified oils of low and high coke formation under commercial conditions.

The process is in operation or under course of construction in Wales, Roumania, India, Java, Borneo, Japan, Trinidad, Curacaosche, Australia, and in all refining centers of the United States such as California, Montana, Wyoming, Oklahoma, Texas, Kansas, Illinois, Louisiana, Arkansas, Kentucky, Maryland, New Jersey and Pennsylvania.

The accompanying flow chart indicates schematically the lay-out of the Dubbs process for commercial use in the cracking of low temperature coal tar or fractions thereof. (See Fig. 8.)

The operation of the process may be carried out by discharging the cracking stock by means of pump A through pipe connection F or E, or both. The cracking stock may be fed into the dephlegmator to act as a cooling medium for the vapors leaving the reaction chamber L or it may

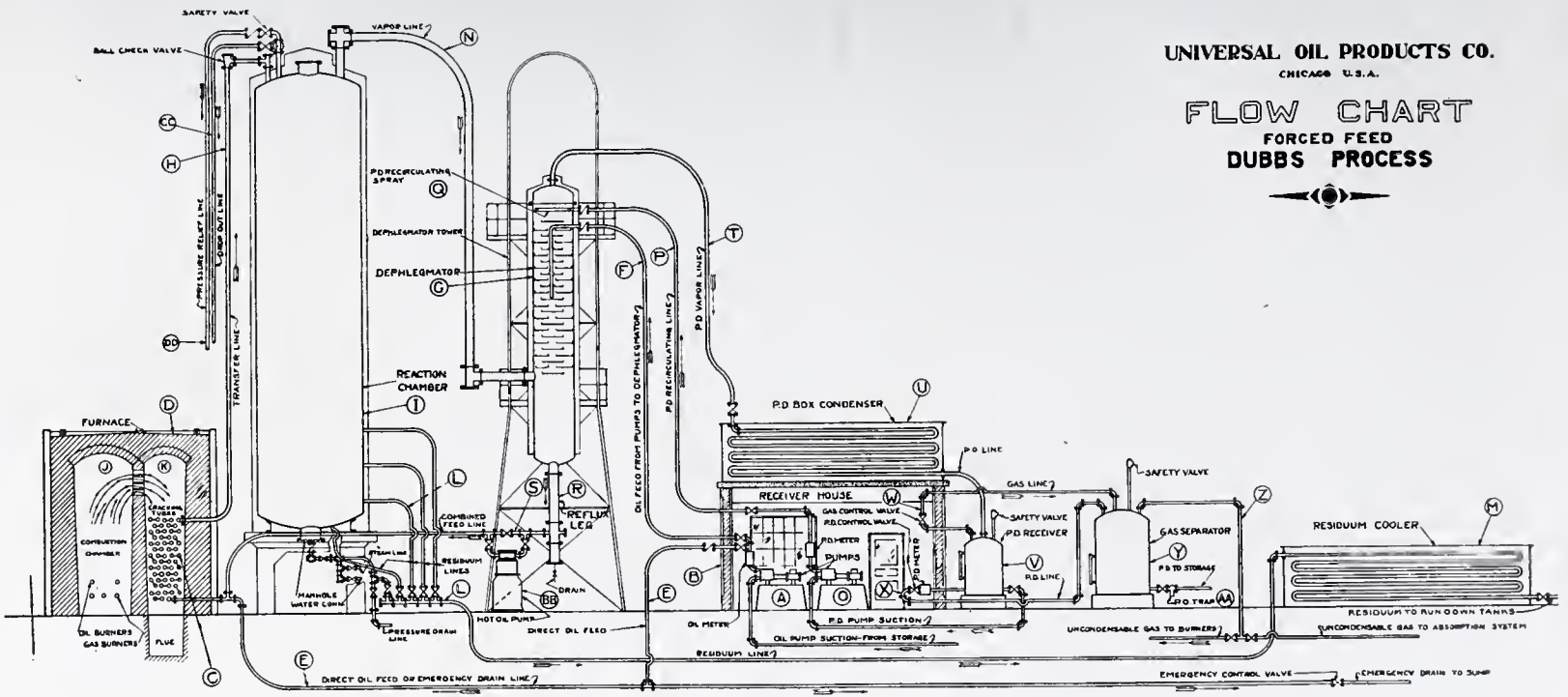

FIG. 8. FLOW CHART—DUBBS PROCESS

be fed in part through line E to the heating coil C placed within the chamber K of the furnace D. The firing may take place in chamber J by means of oil or gas, or both, the products of combustion passing through openings in the wall separating the combustion chamber from the tubes. The cracking stock being heat interchanged in the dephlegmator condenses a portion of said vapor to a liquid product which passes downward through reflux leg R and is picked up by the hot oil pump BB which discharges the oil under pressure through the heating coil C. The hot charging stock and reflux oil enters the continuous cracking tubes and is heated therein from a temperature of approximately 720° F. to a temperature of approximately 850° F. as it discharges through the transfer line into the vertical reaction chamber I under a pressure, depending upon the type of oil undergoing treatment, of 120 pounds pressure more or less. The heated oil is discharged into the reaction chamber which is heat insulated; i. e., all the heating of the oil takes place in the coil situated within the furnace D. No external heat is directed to the vertical reaction chamber or chambers. The heated oil passing into the reaction chamber undergoes further chemical conversion. The vapors from the oil pass through line N to the dephlegmator G wherein fractionation takes place. The temperature of the vapors leaving the dephlegmator is controlled by the recirculation of some of the P. D., or pressure distillate, produced by the process. The sufficiently cracked vapors pass from the top of the dephlegmator through pipe connection T called the P. D., or pressure distillate vapor line. The pressure distillate vapors are cooled in the condenser coil U placed within the P. D. condenser box. The condensed pressure distillate oil containing the motor fuel continues to the receiver V and is continuously discharged from the bottom through a meter and into a gas separator Y at a lower pressure than the receiver. The pressure control on the system is by means of gas valve W. The incondensible gas from the pressure distillate receiver passes on to the gas separator leaving same by means of pipe Z where it may go on to the furnace to be consumed there as fuel, or it may pass on to a gas obsorption system or it may be treated to produce chemical derivatives therefrom. The coke formed during the cracking reaction deposits in the vertical reaction chamber I until

an accumulation of approximately eighty tons in one chamber takes place, or when desirable multiple reaction chambers may be installed.

The operation may be conducted in a manner so as to produce just three products, cracked distillate, incondensible gas and coke. In the event that it is desirable to produce some residual oil for fuel purposes the operation may be so controlled that residual oil is produced, which may be drawn through lines L by means of control valves. The residual oil may be flashed so as to produce a distillate and residue therefrom or it may be cooled so as to be used directly as fuel oil.

The accompanying photographs illustrate some commercial units in operation for the cracking of heavy oils into motor fuel.

THE MISSING LINK IN LOW TEMPERATURE CARBONIZATION

By Clarence B. Wisner

The Carbocite Company, Canton, Ohio

The development of a process is a reaction between an idea, dynamic energy, time and lots of money moving against strong resistance. Frictionless bearings are not, generally speaking, conducive to creative thinking. If things do not go right this mixture is liable to stir up considerable exothermic heat. Patience is of the utmost importance to guard against bringing out an underdone product, or an overtuned mechanism.

Mr. Edison is reported to have answered a call for help on an electric problem with "No, I am too near to the subject; you need the help of a rank outsider." Paradoxical at first glance, it may turn out logical in an occasional instance, as in coal carbonization, where positive conclusions have been drawn from seeming facts, which have bent enough under practice to admit a new principle into the art.

An English technical writer about to release a new book on Low Temperature Carbonization says that he has already listed details of 200 processes with a few more yet to come.*

If the success of a process is measured by its ability to command capital for continued plant duplication, then at the moment none has qualified.

Difficulties in producing coke at low temperatures have been so baffling, and the money spent on some processes so great without convincing issue, that the public is now skeptical as to whether there is any such thing as low temperature carbonization.

But what is a commercial process? Our definition is:

1. Take high ash slack and clean it with air, reducing the ash to that of the coal in place.

2. Solid fuel must not carry more than 13% ash, or 12% volatile.

3. Tar recovered must pay processing cost and cover loss of heat units in solid fuel, by reason of educed hydrocarbons.

4. Solid fuel revenue must pay for the raw coal and leave sufficient surplus to attract capital. It must be of suitable form, strength and density to command popular domestic trade, and finally it must be pro-

* "Low Temperature Carbonization," David Brownlie, in Combustion, New York, April-October, 1926.

duced at a price to compete with domestic sized bituminous coal after market saturation in competition with anthracite and high priced smokeless fuels.

Capacity, because of the low thermal conductivity of coal, must be developed by rapid heating in a constant flowing stream at the highest possible velocity between the heating medium and the coal. Given these conditions, the time cycle from critical vapor eduction point to tar end point may be 40 minutes. This rapid pyrolysis may only be accomplished in the rotary retort, if full values of products are to be conserved.

As a result of our six years of intensive work, we are now able to offer with confidence a new, if radical, principle to the art of low temperature carbonization, of technical and practical interest to the coal world. It is a duel or two-step process, in which an oxidizing thermal pretreatment known as thermodizing brings new conditions under which the solid fuel made in the retort is of a great weight and density as by-product coke made from the same coal. This, of course, is directly opposed to present theory and practice, and at the same moment this view is seemingly sustained by the fact that rotary processes are generally looking to briquetting their residual char for domestic fuel.

The difficulties encountered by the various processes in reaching quantity production bring us to the subject of this paper: The Missing Link in Low Temperature Carbonization.

It is realized that we are now moving on to dangerous theoretical ground and that we may be, figuratively, burned at the stake, by the orthodox school.

Nevertheless, thermodizing means all that the title conveys to low temperature carbonization, and is the logical catalytic agent between practice and process. It is not based upon an unbaked theory, for every condition set forth in this paper has been convincingly proven in practice, and thermodizing is about to be put into commercial use. Well, of course, if it sustains our large scale experimental operations a revolution must take place in orthodox ideas of carbonization practice.

Dual or two stage processes had their inception in two original sources, each, however, from an entirely different angle:

Parr and Layng, at the University of Illinois, working on the theory that if coal be preheated near to the critical vapor eduction point away from air, and then charged into a vertical retort with wall temperature held at 750° C., wherein the charge remains quiescent, carbonization may

be completed autogenously assisted by the exothermic heat generated within the coal during pyrolysis.*

The Carbocite Company, at Canton, Ohio, operates a continuous process.† In a continuous process one may discharge and examine both gaseous and solid products at any stage and temperature, and while we were able to coordinate practice on different types of coal, in many instances it was done at the sacrifice of text book and theory, and we expect the practice developed to have a strong influence on theories of the future. The process comprises two steps:

1. THERMODIZING—Heating the raw coal up near to the vapor eduction point in an oxidizing atmosphere, until its swelling agglutinizing quality is tempered to the extent desired, and then;

2. CARBONIZING—Confining the pretreated coal in a closed container and flooding it with extraneous heat, to maintain the charge at a hydrocarbon vaporizing temperature.

We accepted the rotary type retort as our process medium after due consideration of the difficulties experienced by others, and formed the opinion that they were not insurmountable. One only will be referrd to here, the sticking of the coal to the walls of the retort, which is not inherent in the coal itself but in the manner in which it is treated.

The maximum operating temperature in the steel walls of the retort must not exceed 500° C.; if you drop tar on the walls at a higher heat the light oils boil off, leaving behind a coke residue securely glued to the steel; and this applies to the educed vapors, cracking takes place and amorphous carbon is left behind to carbonize the walls. The trick is so to manipulate the mechanism operating at this low temperature as to get a high heat transfer through the steel.

This is accomplished by direct regeneration; that is, for each pound of charge we circulate 2 to 2½ pounds of heating gas around the retort at high velocity, drawing back the spent gas at some 500° F. to the combustion furnace where 25% of new gas at combustion temperature is introduced and a like amount discarded to the stack. The fresh high temperature gas maintains the desired constant heat with a minimum quantity of fuel.

The maximum load in either retort is 12 pounds per square foot of peripheral surface and fills one-sixth of the cubic space. This light load makes very rapid heating practical, and as we may not go to high temperatures we must move against the steel a large volume of hot gas at

* "Coal Carbonization," Porter, Page 380.
† For more complete description, see Combustion, for June.

high velocity. It is purely mechanical so long as time, temperature, and air constants are recognized and respected. It is operated with unskilled labor in a foolproof manner.

I will mention one more difficulty in the use of the rotary retort in which coal blending is not a satisfactory answer, viz.: the rolling up of the softened coal into balls too big to get out of a gas tight discharger. The larger the ball the higher the heat required to reduce the volatile; in fact, we found it impossible at our maximum temperature to reduce volatile in balls of 6 inches and larger below 16% to 20%.

Coal balls are, we believe, an appropriate name for our solid fuel. It is a product with an exclusive individuality, smooth, irregularly round, of varied shapes and sizes, distinctly differentiated from one-sized artificial briquettes, and is the exclusive product of thermodizing. To make coal balls, we first thermodize the raw coal, that is, we heat and hold it in an oxidizing atmosphere the necessary time to produce the sized balls desired, at a temperature of 250° to 275° C. In this step two-thirds of the entire processing heat is driven into the coal, and the hot dry coal is in ideal condition for completion into coal balls as it flows into the carbonizer. The size is restricted to pass a 3 inch ring and the fines are screened out on a quarter-inch screen; 10% to 15% of fine dust is eroded from the fuel in tumbling through the retort, which may be burned as powdered fuel or fed back into the raw coal.

It is becoming popular with domestic coke users to buy with each ton of coke 500 pounds of breeze, using it to fill the voids and bank the fire at night, giving more uniform combustion. Coal balls when they break from dropping do not crumble, but break into a few pieces. This breakage will never make as much breeze as will be found desirable in burning.

Coal balls are made after a carefully worked out method: At the close of the intumescent period, when all of the tar vapors have been driven off and expansion has stopped, we stop and discharge our product; because at this point coal balls are of maximum weight and density. If carried to a higher temperature, contraction and cracking begin. This critical temperature varies with the type of coal from 400° C. to 480° C.

Domestic fuel stands first in the demands on low temperature carbonization, and that is why we stop at total tar eduction. By stopping here without waiting to get all the gas that would be driven off at our maximum temperature we save about one half of our time cycle and increase our output accordingly, which compensates for the gas left in

coal balls. Because of the perishable nature of the gas, it must be disposed of every hour in the year, offering a very serious difficulty.

Just a word as to the 28 to 32 gallons per ton of tar oils which the coals hereafter mentioned produce per ton of raw coal. It has been stated that its value is problematical. To this we cannot agree. Our tar cracked in an ordinary petroleum refining continuous process at 100 pounds pressure gave:

1. Twenty-two per cent water white motor fuel, 50% aromatic, appraised by competent authority as having a value half way between straight gasoline and pure benzol; it is a no-knock fuel of the highest order, miscible with lower grade fuels, increasing power and decreasing carbon deposits.
2. Thirteen per cent clean tar acids.
3. Fifty-five per cent no ash coke.

The cracking process may be profitably installed at any plant with a tar output of 1000 barrels or over per day.

Tar refiners see value in it above its fuel value and offer long time contracts for production.

Tar should follow petroleum prices, with every evidence looking to increased demand and decreased supply. At present the value of the tar fully meets our specification.

Having in our practice cut out salable gas, we answer the question, "What about it?" with the statement that a constant hourly supply does not fit a 12 hour or a 6 months peak demand, and that blue water gas regulated to the demand, made at the point of consumption, is the most economical and cheapest supply for both industrial and domestic fuel purposes; and that coal balls are the ideal source from which to make the gas.

Having told you briefly of our practice, I want to tell you of demonstrations made with the types of coal that provide the bulk of the country's domestic fuel. When we first undertook to thermodize Pittsburgh No. 8 coal which you will recognize as our greatest coking coal, it looked as though we had reached our Waterloo. The effect of air was negligible when we crushed all through a three-fourths inch screen. Reducing the size to pass all through a three-eights inch screen partially restricted agglutinizing, but we were not able to completely kill it on this size. This is where we made our first balls so large that tumbling in the retort sounded like a foundry rattler. Practice brought sizes to a predetermined specification.

Moving over the Ohio State line, the No. 6 vein predominates, a highly volatile, high oxygen, and violently swelling coal. Carbonized direct, the solid fuel was of the consistency of pop corn and weighed 17 to 19 pounds per cubic foot; adding coking coal as high as 30% gave about 50% of weak, unmarketable balls. A little air in thermodizing killed any coking tendency, and we finally found the solution in a blend of 85% of No. 6 with 15% of No. 8, but not without the air pretreatment. We then produced 85% coal balls weighing 27 pounds to the cubic foot, meeting our specification in every particular.

We have processed three types of Indiana coals without blending and a fourth requiring slight blending. In each instance the coal balls weighed 27 pounds, which is the same weight as by-product coke of equal size made from the same coal in the ovens at Terre Haute.

Having processed these various coals, we believe that domestic coal balls may be commercially made in practically all of the mining districts throughout the country. You will appreciate the superiority of these natural coal balls containing a uniform gas content which burns with a pleasing flame until entirely consumed—without smoke or odor and clean. Briquettes have a prohibitive cost in competition with cost-free coal balls. These features have caused coal operators to offer raw coal for a plant now building in exchange for coal balls at a satisfactory spread in price to meet the financial side of our specification.

We see Parr and Layng calling for the total exclusion of air in their preheating, positive that any oxidizing influence would be fatal to their process and depending alone on blending to overcome swelling and get proper weight and density in their solid fuel.

Now we come before you just as positive that present theory and practice inherited from by-product practice are wrong and not applicable to low temperature carbonization. Twenty-five years of research and experimental practice have not advanced the art into commercial low cost production. We believe that the solution of the problem is at hand, and offer thermodizing as the liaison between process and practice. Paradoxical as it may seem, high oxygen coals require an oxygen bath to increase weight and density, in which oxygen may be extracted and not absorbed, evidenced by weight of coal balls. Until we know the reason why, it certainly looks as if some legerdemain takes place when we see

fine coal tumbled loosely through a rotary retort and discharged in coal balls of the same weight as by-product coke made from the same coal.

But these seemingly radical statements are based on convincing demonstrations, which indicate that low temperature practice must be entirely divorced from high temperature theories. We do not deny that we are earnest students of theory and practice of the world's greatest fuel problem; but indifferent as long as we can save 90% or better of the heat units contained in the raw coal at a minimum cost and produce the highest quality products.

DISCUSSION

H. C. PORTER. I was very much interested in Mr. Parker's account of the Bussey process and particularly his statement that he can reduce sulphur in coal. At least, in one example he gave from 4% in the coal to 1% in the coke. I wish Mr. Parker would be so good as to give us a little indication as to how he does that. That is a very important thing to do.

RICHARD B. PARKER. To be perfectly frank, Dr. Porter, I am not at all sure how we do it. It is apparently due to the introduction of steam at the base of the retort. If we leave the steam out we do not get the reduction. When we put the steam on, the sulphur is very much reduced in every coal processed. We don't know why.

H. C. PORTER. Have you noticed any increase of H_2S and CS_2 in the gas?

RICHARD B. PARKER. Yes.

H. C. PORTER. I should like to ask if quantities of gas recovered are not unusually large, 20,000 to 30,000 cubic feet?

RICHARD B. PARKER. The large volume of gas is undoubtedly due to the producer action obtained by the introduction of air and steam at the base of the retort and the consequent dilution of the gas produced by the nitrogen introduced and the carbon dioxide formed. If we reduce this dilution by heating, without the admission of steam or air, the total gas produced is reduced to 7,000 or 8,000 cu. ft. of higher B.t.u. As we normally run, the total B.t.u. produced from the coal charged are distributed through the diluted producer gas, and the gas analyses which I didn't read, indicates the presence of nitrogen and CO_2 in sufficient quantities to account for the increased volume.

F. C. GREENE.* I am very much interested in that, Mr. Parker, about the reduction of sulphur, and I agree with Dr. Porter that if we can reduce our sulphur it is a most important thing. Our sulphur in southerin Illinois coal will run somewhere, we will say, between 1.2 to 1.4%, and I am much inclined to think that the coal from which I will quote some analyses made from some of our products contained

*Combustion Engineer, Old Ben Coal Corporation, Chicago, Ill.

about 1.7% sulphur in the screenings. We would probably carbonize to seventy, maybe eighty, per cent yield; so that when I read to you that our sulphur in the char product in one case was 1.08% and in another 1.11%, which would result from an eighty per cent carbonization yield, there would be in the original coal 0.3% or 0.4% out of 1.4%, which would mean about only one-fourth to one-third of the sulphur might have been reduced in the char. The classic figure for reduction in coking is 0.4%. Now, the point that I would like to have cleared up, because it is important, is your thought that it may be due to the steam. If that is so, that steam had a very high temperature,—as does ours as probably you observed this afternoon in the paper that I read, when all of our extracts, amounting to ten or twelve per cent, are out of the coal. Our coal feed ascends and is subjected to a very high temperature and pressure and then descends through the coal. Now, Mr. Parker, you have a very highly heated steam atmosphere, and you get the reduction of sulphur in such atmosphere and attribute it to that. How does it come that under a similar condition, we do not get similar results?

RICHARD B. PARKER. The presence of oxygen together with the steam may have something to do with it. Just what happens, I don't know. But we don't find the sulphur in the coke.

F. C. GREENE. Whatever it is, let us know. It means much to us.

H. F. SMITH.* We have recently conducted some experiments that perhaps throw some light on the matter of sulphur reduction. Several coal samples examined were found to contain three distinct sulphur compounds: one decomposing at about 1050°F.; one at about 1250°F. and one at about 1675°F. The first two are probably organic compounds and the last pyritic. After any thermal decomposition there is a rearrangement into new compounds, the percentages of each formed being determined by the reaction tendency and the relative concentration of reaction products. Sulphur liberated from its original compounds in coal will recombine in part with hydrogen to form H_2S and other gaseous compounds and in part with carbon to form non-volatile compounds which remain in the coke. Increasing the percentage of hydrogen as by introduction of steam will increase the proportion of gaseous sulphur compounds formed and thus reduce the percentage left in the coke. It is obvious, however, that reduction of sulphur in coking cannot occur at temperatures lower than the decomposition points of the sulphur compounds originally present in the coal. One would therefore expect no sulphur reduction for coking temperatures below 1050°F., and no very great reduction until a temperature of 1250°F. is exceeded.

CHAIRMAN WILLIAM E. FOHL. Would your explanation be adequate, Mr. Smith, in the face of the temperatures that are used here,

*Secretary and Manager, Smith Gas Engineering Company, Dayton, Ohio.

lower than the ones you quote? You speak of these temperature points at which certain parts of sulphur decompose.

RICHARD B. PARKER. That is all right. Our finishing temperatures approach the ones which Mr. Smith cited. Our finishing temperature isn't 800°F., but is nearer 2000°F.

ALFRED T. CHILD.* The results described by Mr. Wisner are parparticularly interesting to me because I obtained the same type of product in the course of some student thesis work conducted by four of our students during the spring of 1922. They were working on Fifth Vein coal (Ind.) using a small rotary retort. Something happened in the course of one experiment that caused a shut-down and when the retort was opened approximately 60% of the coal had "balled," with the balance as fine breeze. The material was the size of a hen's egg and smaller.

The question has been raised as to whether sulphur is removed in the low temperature process. I know that a considerable amount is volatilized, as we had an iron oxide purifier in the train. This purifier became so hot that the paint peeled while the experiment was in operation, indicating the very rapid rate at which sulphur was being absorbed.

In regard to sulphur being removed by the water gas reaction I would like to state that the water gas reaction requires a temperature of close to 1000°C., a temperature not attained in the low temperature. In the high temperature process it is commonly conceded that half the sulphur in a given raw coal remains in the coke and the balance is divided between the tar and the gas—mostly in the gas, I believe.

I would like to emphasize a point that I believe we have not stressed sufficiently in our discussions—namely the psychology of the problem. I believe that research on low temperature carbonization processes has now gone far enough to say that such processes will become commercially successful if and when there is a general demand for the product. Such a demand depends largely on three conditions. First, sufficient education of the public to demonstrate the evils of smoke, as for example on health—especially on children, the damage of soot and sulphurous acid on all kinds of physical equipment and the increased cost of cleaning, and finally the general lowering effect on the general tone of a community. Second, the product must be such that people will be able to learn to use it easily, that is, kindle easily and be used in present equipment. Of course it must be properly sized and stand shipment.

Finally, it must be sold at an attractive price, that is less than current prices for domestic high temperature coke.

A MEMBER. I would like to ask Mr. Egloff a question; whether the oils are first cracked—can you crack your low temperature tars as

*Associate Professor of Chemical Engineering, Rose Polytechnic Institute, Terre Haute, Indiana.

they come from your low temperature process or do they have to be distilled first?

GUSTAV EGLOFF. Without question, we can and do crack them as they come from the low temperature process.

A MEMBER. Do you attribute any anti-knock properties to the bodies themselves?

GUSTAV EGLOFF. My answer to the question, "Do you attribute any anti-knock properties to the bodies themselves?" is that the hydrocarbon bodies of high anti-knock properties are produced by means of pressure distillation from the low temperature tars. The anti-knock properties of gasoline are inherent in the type hydrocarbons which would be mainly of the aromatic series produced from the low temperature tar cracking. There is no necessity for pretreating the low temperature tar received for the removal of any of its bodies.

F. C. GREENE. Mr. Parker, I am interested in your process on account of our process. We will have quite a lot of producer gas, and it just occurred to me that you might be able to make producer gas for us cheaper than we can make it. What I had in mind was this; with our moisture we figure our producer gas just about the B.t.u. point that you did, but we have to first scrub that gas before firing with it. After your gas goes through your recovery apparatus it is about 225 B. t.u. Is your gas clean and cool? Would you consider that it is good gas for firing as compared with the gas from a standard producer?

RICHARD B. PARKER. Yes, we think so. At the plant at Louisville it is burned under the boilers in an open flame, and an open air torch was burned for weeks at the Louisville plant without blowing out. Under normal operating conditions the average net B.t.u. in the gas is about 250.

FRANK M. GENTRY.* Low temperature carbonization of coal by the sensible heat of hot producer gas, obtained from the complete gasification of a portion of the semi-coke in the lower regions of the retort, has been attacked in the United States by Bussey and a few others. In Europe this principle seems to have been used successfully by Maclaurin and Lymn. The latter attained this end by elongating the Power Gas Corporation bituminous coal producer, based upon the Mond design, and changing the position of the gas off-take so that the hot gas could dissipate its sensible heat in passing through the charge. It is not at all surprising to see that low temperature coke can be obtained from ordinary producers by the simple expedient of speeding the throughput and increasing the thickness of the superincumbent layer of raw coal. As Mr. Parker pointed out, semi-coke from the Bussey process is com-

*Assistant to Consulting Engineer, The New York Edison Co. Submitted in writing after close of meeting.

paratively dense, so that it is seen that the superincumbent layer performs additional service by compressing the soft coal in the plastic zone.

Someone has brought out the fact that, while the sulphur in the semi-coke was considerably reduced by steaming in the Bussey Process, such was not the case in another low temperature process, which was externally heated. This should not be considered extraordinary when one recalls the difference in temperature of the hot zone of the producer and the hottest zone in the externally heated retort. It has been conclusively demonstrated that the higher the temperature of carbonization the less sulphur remains in the coke. I have in mind some tests with a coal containing 4.25% sulphur whose semi-coke at 400° C. contained 2.30% sulphur and at 600° C. only 0.83% sulphur, the residual sulphur being largely in the form of sulphides. Conversely, with increasing temperature of carbonization the percentage sulphur in the tar and gas increase.

Maclaurin is said to have been quite successful in his experiments. In his early work with the Port Dundas retort he separated the producer and low temperature zones in order to prevent the high ash of the semi-coke, which is often put forward as an objection to this method. Later in his Grangemouth and subsequent retorts he did not adopt the dual retort design, believing that a large part of the ash would sift out in the breeze. Tests confirmed his belief in this respect. Thus, starting in one case with a coal whose ash content was 8.1% he found that the large lumps of semi-coke contained 13.5% ash, whereas the breeze contained 33.4%. Experiments show that coals differ greatly in the percentage ash retained by the large lumps, the increase varying from a very few per cent. to perhaps 100%.

Mr. Wisner has told us of his success in the use of a two stage process, the preliminary heat treatment serving to destroy excesses of certain undesirable constituents in the coal. His results are in agreement with others who have adopted preheating of the charge to produce the same effect. Thus Parr from fundamental research on the constitution of coal found it advantageous with high oxygen non-coking coals to slightly predistil the charge at 350° C. before actual carbonization and Illingworth, after independent research, adopted the same procedure. Bone many years ago discovered the effect of partial oxidation upon the coking qualities of coal even at as low a temperature as 108° C. under prolonged exposure to oxidation.

During this conference we have heard papers from men associated with two other processes using horizontal rotary retorts, the Nielsen Process and the Thyssen Process. In one of my discussions of another paper I mentioned that the Fusion Process which is of this type is said to have had successful operation in England. In Germany the horizontal rotary retort has been a great favorite for the purpose of low temperature carbonization. In this connection should be mentioned the

Fellner-Ziegler Process and the Stinnes Process. Both of these processes are externally heated. The chief point of novelty in the Fellner-Ziegler Process is that a scraper is provided for about the first 40% of the retort's length to remove the crust of caking coal which forms on the inner surface. The unique point in the Kohlenscheidungs Gesellschaft, or Stinnes Process, is the use of two concentric rotary retorts, the inner of which is equipped with spiral flights to transport the coal. The charge makes a double passage through this retort, first through the inner cylinder where it is preheated and then through the outer cylinder where actual carbonization takes place.

In concluding my discussion, I would like to point out certain facts that are well to bear in mind when considering the economics of low temperature carbonization. In the first place, while industry has adjusted itself to absorb certain of the by-products recovered from present practice in the coke and gas industries, experience has shown that even now large quantities of these products, particularly the tar and gas, are burned as fuel or wasted through lack of sufficient market. Just how rapidly the markets can continue to absorb additional quantities of by-products without disturbing the prices, which even now yield no very handsome profit, is a conjecture which is contingent upon the development of new uses. In the second place, despite general belief to the contrary, low temperature carbonization for production of solid fuels can hardly be justified at the present time from the standpoint of conservation of our national coal resources. The yield of solid fuel is about 30% less than the coal carbonized, so that the consumption of raw coal must be increased by at least that amount to provide the solid fuel for domestic and certain industrial uses. Klingenberg, from his investigations of by-product recovery in central electric stations, came to this conclusion. The only justification for low temperature carbonization is that which will naturally develop in the normal course of private enterprise. In other words, the industry must stand or fall on its ability to show a satisfactory yield on the capital invested by the recovery and sale of by-products, in the case of central electric stations through reduction in the cost of power and in the case of industrial and domestic solid fuel consumers through its ability to effect some reduction in the cost per unit of available heat in the fuel. Despite the demand for motor fuel and lubricating oils, their production from coal by low temperature or any other means of carbonization cannot be economically considered unless a saving accrues to the consumer of the residual coke, either through its increased efficiency or through reduction in cost over the raw coal.

LIST OF DELEGATES

Colleges and Universities

Alabama, University of
S. J. Lloyd

Albright College
E. A. Miles

Amherst College
F. B. Loomis

Case School of Applied Science
A. W. Smith
F. H. Vose
W. R. Veazey

Center College
J. B. Brown

Colorado College
S. L. Goodale

Colorado School of Mines
C. B. Carpenter
L. S. Grant

Columbia University
J. J. Morgan

Dalhousie, University of
F. H. Sexton

Denver, University of
J. H. Cover

Drexel Institute
E. N. Calhoun
L. G. Sigafoo
R. L. Ehmann

Earlham College
F. R. Charles

Ecole Normale Superieure, Paris
J. Bing

Geneva College
P. L. Coon

Georgetown University
G. L. Coyle

Hampden-Sidney College
R. B. Woodworth

Harvard University
L. S. Marks

Illinois, University of
A. C. Callen

Illinois, University of
Engineering Experiment Station
A. P. Kratz

Indiana University
W. N. Logan

Iowa, University of
H. L. Olin

John Hopkins University
W. J. Huff

Juniata College
D. M. Heider

Kansas, University of
P. F. Walker

Lehigh University
E. Sinkinson

Macalester College
J. L. Sheean

Mexico, University of
A. Cornejo

McGill University
L. R. Thomson

Michigan, University of
A. H. White

North Carolina, University of
F. C. Vilbrandt

North Dakota Agricultural College
R. M. Dolve

North Dakota, University of
A. W. Gauger

Northwestern University
F. C. Whitmore

Ohio University
W. B. Bentley

Pennsylvania College for Women
S. M. Griswold
E. K. Wallace
E. I. Quaintance
M. S. Skinker

Pennsylvania State College
E. A. Holbrook
G. L. Wendt
E. D. Ries

Pennsylvania, University of
R. H. Fernald
W. A. Sloan

Colleges and Universities *(Continued)*

Pittsburgh, University of
F. L. Bishop
R. M. Black

Pittsburgh, University of
Mellon Institute
G. D. Beal
H. J. Rose

Princeton University
H. S. Taylor

Purdue University
E. C. Elliot

Rensselaer . Polytechnic Institute
A. S. Davison

Rose Polytechnic Institute
A. T. Child

Stevens Institute of Technology
C. Miller

Texas Agriculture and Mechanical, College of
F. C. Bolton

Tokio Imperial University
Y. Oshima

Trinity College
J. B. Moore

Washington State College
W. F. Huppke

Washington, University of
C. R. Fettke

Washington and Jeefferson College
A. H. Wright
C. V. Bowen
A. Lyle

Westinghouse Technical Night School
R. W. Ahlquist

Westminster College
J. G. Lutz

West Virginia University
C. D. Lawall

West Virginia Wesleyan College
N. Hyma

Whitman College
G. R. Greenslade

Worcester Polytechnic Institute
M. E. Smith

Yale University
Sheffield Scientific School
W. J. Wohlenberg

Foreign Societies

Canadian Institute of Chemistry
M. L. Davies

Canadian Institute of Mining and Metallurgy
C. Camsell
A. M. Irvine

Coal Research Club, England
R. Lessing

Comite Central de Houillers de France
C. E. Heurteau
M. Winkler
M. Coing

Deutsche Chemische Gesellschaft
F. Paneth

Deutsche Bunsen Gesellschaft
F. Paneth

Gesellschaft Deutscher Naturforscher und Aerzte
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Institution of Fuel Technology, England
R. Lessing

Institution of Gas Engineers, England
G. M. Gill

Institution of Petroleum Technologists, England
R. Lessing

Le Comite Central des Producteurs et Distillateurs de Goudron
J. Bing

National Research Council, Canada
F. E. Lathe

Royal Society of Arts, England
R. Lessing

Societe Belge de Recuperation Industrielle
E. Kroch

Societe de Chimie Industrielle
J. Bing

Societe des Ingenieurs Civils de France
G. Patart

FOREIGN SOCIETIES *(Continued)*

SOCIETY OF CHEMICAL INDUSTRY, ENGLAND
Fuel Section
G. M. Hill
C. H. Lander
R. Lessing

SOCIETY OF FUEL TECHNOLOGY, JAPAN
Y. Oshima

SYNDICAT PROFESSIONNEL DE L'INDUSTRIE DU GAZ
J. Bing

WORLD POWER CONFERENCE
International Executive Council
O. C. Merrill

AMERICAN SCIENTIFIC SOCIETIES

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE
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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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A. Knapp

AMERICAN CHEMICAL SOCIETY
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H. E. Howe

Erie Section
G. S. Brewen

Pittsburgh Section
A. C. Fieldner

University of Illinois Section
S. W. Parr

University of Michigan Section
A. H. White

AMERICAN CONCRETE INSTITUTE
P. J. Freeman

AMERICAN ELECTROCHEMICAL SOCIETY
J. J. Morgan

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AMERICAN PAPER AND PULP ASSOCIATION
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W. E. B. Baker

AMERICAN PETROLEUM INSTITUTE
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C. O. Johns

AMERICAN PHARMACEUTICAL ASSOCIATION
J. A. Koch

AMERICAN PHYSICAL SOCIETY
H. S. Hower

AMERICAN SOCIETY FOR MUNICIPAL IMPROVEMENTS
N. S. Sprague

ASSOCIATION OF AMERICAN STATE GEOLOGISTS
W. A. Nelson
M. M. Leighton

COAL MINING INSTITUTE OF AMERICA
E. Steidle
M. D. Cooper
E. D. Dunbar

ELECTRIC STEEL FOUNDERS' RESEARCH GROUP
R. A. Bull

GEOLOGICAL SOCIETY OF AMERICA
G. H. Ashley
C. R. Fettke
D. White

INSTITUTE OF ECONOMICS
F. G. Tryon

INTERNATIONAL RAILWAY FUEL ASSOCIATION
W. L. Robinson
E. E. Ramey

NATIONAL ACADEMY OF SCIENCES
D. White

NATIONAL COAL ASSOCIATION
W. Barnum
H. L. Gandy

NATIONAL FERTILIZER ASSOCIATION
C. J. Brand

NATIONAL RESEARCH COUNCIL
W. J. Hale
J. F. Norris
D. White

NATIONAL SAFETY COUNCIL
C. B. Auel

NATIONAL WOOD CHEMICAL ASSOCIATION
M. H. Haertel

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PROCEEDINGS
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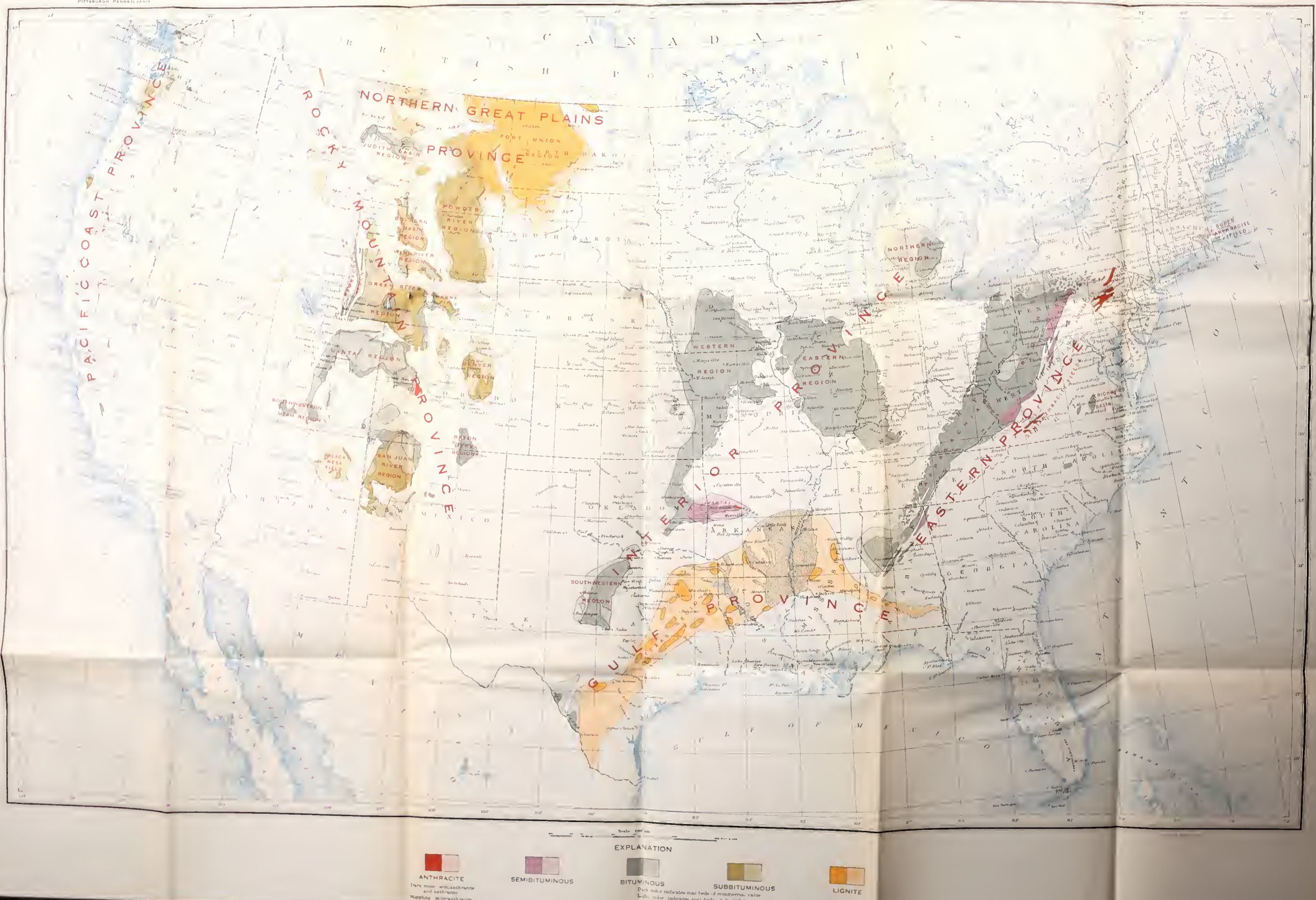
COAL FIELDS OF THE UNITED STATES

BY MARIUS R. CAMPBELL

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